CHALMERS
UNIVERSITY OF TECHNOLOGY


# Construction Labour Productivity

## Botrygg Case Studies

Master’s Thesis in the Master’s Programme Design and Construction Project Management

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Labourers working on a Botrygg work site in Örebro

Department of Architecture and Civil Environmental Engineering Göteborg, Sweden, 2017

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# Abstract

The construction industry in general is a labour centric industry. Labour productivity is a critical factor that determines the success of a construction project. Many researches have pointed out the labour productivity is dependent on working conditions, quality of management and technology.

This report aims to measure labour productivity using benchmarking method of projects productivity. It also identifies the factors responsible for the reduction in the rate of labour productivity using the activity analysis, work sampling method and interviews with Botrygg AB's site manager. Botrygg Bygg AB is both the client and the executive contractor for its projects. The company outsources the design work and does the construction work by itself. The employees are from Romania and are stationed to stay in accommodations which are provided by Botrygg AB and located in a nearby location at their project sites.

The research was carried out with the help of methods adopted from the literature review. The literature review covers factors impacting on labour productivity decline from different articles in countries such as Egypt, Kuwait and Sweden. It covers also statistical figures of waste in the construction due to non-value-added activities. These index figures were taken as the foundation base and evident to show a descending trend in labour productivity rate in projects outputs. Two measurement methodologies of productivity benchmarking and activity analysis were reviewed and applied in the empirical part explicitly.

Those two methods were adopted in different countries to assess and measure project´s labour productivity. The first method of productivity benchmarking measured the project´ attributes of baseline productivity and project waste indexes (PMI). This methodology was applied on three case study projects of Tyresö, Övre Vasastaden and Fallskärmen to access their labour productivity rates. These projects were executed during three different time periods by Botrygg Bygg AB. The result of this benchmarking indicated a significant decline and remarkable variation in their labour productivity rates. This result was reached by comparing those three projects baseline productivity attributes of (WH/M2) together.

To validate this result, the performance metric system of activity analysis was applied on Fallskärmen residential project´s reinforcement task to analyse the laborers direct work. The analysis involved the site observations and data gathering to identify those unproductive activities which did not add any value on the construction work. The analysis resulted in about 25 % of construction time as value added and 75 % as non-value-added activities. This outcome has negatively impacted on the labour productivity in the entire project. The analysis indicated also many gaps in implementation practice of the reinforcement task elements which have influenced on labour productivity decline. Those gaps which were direct reasons to waste valuable construction time were the laborers walking time empty handed, material movement, waiting for material arrival and equipment set up.

Other general impacting factors emerged through the site visits and gathering information from Fallskärmen site manager during interviews. As such the design incompatibility to the sight condition due to different outsourcing of design procurement and the challenge with the ground´s geological condition were issues in pre-construction stage. As well as lack of using buildability by the designers to simplify the design attributes and using of MS Power project software were found as major factors. While the request for information (RFI), type of cast-on-site construction method and logistical delays contributed in reducing the productivity during the construction stage. Also, other factors which had a negative implication on the workforce´s productivity were material quality, overtime work and some human reasons.

Based on the gaps detected through applying the activity analysis and weaknesses were found through site visits and interviews, some improvement strategies have been proposed. Those improvements cover both technological and managerial aspects which would increase the work flow and will give access to information when required. Using of BIM as 3D model and adding the 4D of the time function will help the site manager and sub-contractors to understand and tackle conflicts better. BIM use shorten the distance between the project´s potential stakeholders and supplies a closer communication in material delivery. The usage of drones on site will reduce time and can be very fruitful in discussion with designers and monitoring safety and work progress. The managerial recommendations dealt with having design managers meet the site managers while designing, and to provide works incentives to boost their morale. Assigning a well secured Work Breakdown Structure (WBS) prior to deadline of each activity finished or start. Better site equipment management to have enough for every activity to avoid substituting machinery with the human efforts which is more time-consuming construction work.

Keywords: Labour productivity, Benchmarking, Work Sampling, Botrygg Bygg, PMI.

# Contents

# Preface

This thesis marks the conclusion of our master's Programme in Design and Construction Project Management at the Chalmers University of Technology. This has been a wonderful learning experience for us, the thesis has given us an opportunity to get a first-hand experience of onsite as well as offsite activities.

Firstly, we would like to thank Professor Cristian Koch for his able guidance and support which helped us to successfully complete this thesis. We would also like to thank our friends and family members who have supported us in this research.

This thesis has been done with Botrygg Bygg AB. The Company has helped us generously with special thanks to Mr. Hogar Lak, Site manager at Botrygg Bygg AB for his colossal efforts and dedicating his time for our interviews and site visits. We also thank Bootrygg Bygg for providing us data which was vital for the completion of this thesis.

# Notations

BP Baseline Productivity attribute

PWI Project Waste Index

PMI Project Management Index

PR Performance Ratio

CP Cumulative Productivity

GDP Growth Domestic Product

ICT Information Communication Technology

MSPP Microsoft Power Point software

RFI Request for Information

WSM Work Sampling Method as activity analysis

CAM Computer Aided Manufacturing

CAD Computer Aided Design

BIM Building Information Modelling

WH/m2 Work Hours per Square Meters

WBS Work Breakdown Structure

# List of Figures

# List of Tables

# 1 Introduction

## 1.1 Problem´s Historical Perspective

Swedish construction industry is criticized for being a low productive and a high production cost. Labour wages and building material prices increase due to the demand for construction work (Forsberg, 2016). As the prime aim of the construction market is to make profit with minimal investment, it is therefore important to produce more units with the same input (Forsberg, 2007). Therefore, it is important to understand the main determinant factors impacting on productivity to keep an accurate record on the project's labour performance (Enshassi et al, 2007). Any decline in the project´s output work would have significant and negative implications in the final profit which eventually would not cover the cost of material and labour charges. Implying a great loss of economy and the country´s GDP (McKinsey Global Institute, 2017).

## 1.2 Specific Problem formulation

The construction industry has been found to be not as successful in improving productivity and performance as the manufactory sector (Harrison ,2007). Therefore, according to Haas, the labour productivity improvement and projects´ performance measurement have always been a challenge in the construction industry (Haas,2017).

The Swedish government expresses its worry about low labour productivity and the productivity development in the Swedish construction sector. Therefore, this situation needs an effective improve in labouring efforts to increase value added activities. Also, to reduce high rate of non-value-added activities which are estimated between 30-35 % of waste in construction time. This waste relates to how the craftsmen use working hours to transfer it into the value-added work flow which was accounted for only 17,5 % and the preparation works for 45,5 % of their total time (Jonsson, 2015; Josephson and Saukkoriipi, 2005). An effective usage of time is a major factor to focus on. (Alinaitwe et al., 2005; Hammarlund and Ryden,1998) have indicated that laborers have only used about 3,5 hours out of 8 hours working shift on productive activities which added value on construction.

As the construction work is highly dependent on people's efforts therefore it is more labour power oriented. According to (Chan and Kak, 2007) the construction labour productivity is a crucial performance measure of construction's core activity, i.e. on-site production of a built facility.

Since innovations and new ideas are slow in the construction industry due to the risk in implementing new methods, it has always been a focus on how to make things better with in the existing framework of things. Therefore, lack of having both labour performance and productivity measurement methodology for contractors, at the firm level, represents a serious gap in construction research. According to (Fisher et al, 1995) to improve something we need to measure it and this measurement could be achieved through project benchmarking process.

Labour productivity is a complex, multi aspect issue which it´s level and dynamics are affected by a variety of factors. As such there is inevitable need to study practical tools to identify the affecting factors associated with this productivity.

Some companies adopt prefabrication method of construction where the labour power is not extensively dependent. While in other companies cast-on-site method is more dominated which entirely relies on labouring power. This research is adopting both construction methods, accordingly this case study company of (Botrygg AB). Botrygg AB was targeted as the most proper case which highly depends on labour power. The site manager and the quantity surveyor were responsible for the newly built project of five levels residential apartment building in Fallskärmen located in Örebro. They were also in charge of two other multi-storey residential projects of Tyresö in Stockholm and Övre Vasastaden project in Linköping, Sweden.

## 1.3 Research´s Aim & Contribution

The aim of this research is to measure the labour productivity in construction projects and assessing projects productivity variations. Also, to identify the management gaps in practice implementations which affect projects´ lower labour productivity. As well as to find and recommend effective improvements for the site managers to mitigate the source of risks which can lead to waste in construction time.

## 1.4 Research Main Questions

1. What are the major relevant factor areas that influence labour productivity on construction sites in Sweden?

2. How do you measure the construction projects labour productivity?

### 1.4.1 Research´s sub-questions

3. How is a projects labour productivity benchmarked and which methodology is used to do so?

4. How does WSM helps to detect the existing gaps in the management practice elements which decrease adding value onto the construction work?

5. What are the improvements that can be brought about in the case studies discussed to mitigate the factors responsible for low labour productivity?

6. How non-value-added activities influences projects labour productivity?

# 2 Methodology

The keywords Benchmarking construction productivity, construction labour productivity, labour performance decline, construction performance measurement and impacting factors on labour productivity were used in searching for relevant articles. Those words were used to an online web search in finding of academic publications and database of international journals and articles. Nine search engines have been utilized in the searching process such as, i.e. " Chalmers Summon library database "," Google Scholar”," Web of Science" and "Engineering Village", “ScienceDirect “, “Elsevier”, “compendex”, “Scientific Information database” and Scopus for collecting academic articles and publications related to the topic.

About 50 hits that were found on labour productivity in construction industry and impacting factors which result into waste in construction projects. Some of those articles which were more task based oriented have been utilized from other international Universities of Waterloo in the researching study. Those selected articles and publications being relied on in this research´s theory was about construction projects benchmarking and the labour productivity rate. In the researches theory articles of productivity in construction by (Dozzi, S.P, AbouRizk, 1993) and Development of international benchmarking metrics by(Haas,2017) were argued in detail.

Thomas and Zvarski’s measurement model of construction productivity benchmarking was adopted in the theory part to demonstrate the problem with the research topic. (Enshassi et al, and Haas, 2017) articles of benchmarking model and Jossephson & Saukoriipi article of waste in previous construction projects were relied on to build up the theory by showing the statistical data of waste in labour time and reduction concerning the labour productivity rate. Haas and Dozzi, AbouRizk methodology of activity analysis was used to classify site activities on three different parameters of support, non-productive and productive work. This methodology was applied to identify factors and to find gaps in the practice elements which were responsible for reduction in projects´ productivity and set up improvement strategies. Productivity variations between different projects from international journals were reviewed by showing graphs and statistical values to establish for a wide argument in the empirical part.

In the empirical part, the topic has been studied, a qualitative study of several semi-structured interviews was conducted to collect data and knowledge by asking "What " relevant factors and "How " they have impacted on reduction in labour productivity. The interviews took place via skype and face to face interviews on site. Each online interview lasted approximately 1,5 hours. The face-to-face interviews took place more than two hours during 4 times of the site visit. All of interviews were conducted through asking open ended question, the questions were already sent to the interviewee few days prior to the interview. The interviews were recorded, transcribed and analysed. The interviewee shared his perspective which was self reflecting on his own work experiences. The site visits and interviews were agreed upon previously according to a time schedule which was organized in coordination with the site manager one month in advance. This time schedule and the research topic were approved and accepted by Botryggs HRM department to be handled by the respective site manager.

A qualitative questionnaire form was provided by the site manager which showed affecting factors on labour productivity reduction and the non-value-added tasks. The form indicated a combination between the waste factors and the influence of this waste on project´s productivity during the preconstruction and construction stage. It illustrated specific hints, deviations, and gaps in management practice elements which were taken from Botryggs previous projects. Actions that were taken by the company to increase projects efficiency were indicated in the form.

On-site pictures to the building structure of certain elements were attached under those sections which required more clarifications to explain potential defects which resulted in construction interruption and rework. The percentages indexes of value added and none-value-added activities in construction work have been showed in tables. Graphical figures of the baseline productivity attribute were showed to illustrate where exactly the labour productivity has ended up for all Botryggs targeted projects.

The recommended management improvement strategies were classified according to the actions to be taken and waste reasons to be mitigated by shortlisting them in a table. The proposed solutions were included with respect to each gap which was found in the targeted activity elements.

## 2.1 Productivity benchmarking model of Thomas & Zvarski

Mainly this model´s methodology relates to total work hours to the total quantities of work done in Botrygg´s three projects which were subjected to a significant variability in labour performance. The result of comparison between Botrygg´s case study projects´ baseline productivity attributes was analysed through a graphical chart form to demonstrate the descended changes in labour productivity.

Different mathematical equations of this model were applied to measure projects baseline productivity attribute as the ratio of total WHs with respect to total quantity areas of reinforcement produced m2 as (wh/m2). Other equations were used to measure PMI and PR. The measured indexes for all projects baseline productivity were represented and indicated in the graphs by positioning the average of baseline productivity by drawing a line for each respective project. Also, the graph showed which project had experienced the best performance among all. Index results for all targeted projects attributes were shown through values in a table in the comparison section.

The tools which has been used to collect information, was a data calculation spreadsheet form three case study projects which contained entire materials, labour hours, all square meters of area produced for all the tasks involved in those projects. But only the labour hours spent, and the number of square meter reinforcement areas data have been accounted for in measuring the performance parameter of baseline productivity. The data which were chosen from the spread sheet was from all three projects of Tyresö, Övre Vasastaden and the current ongoing of Fallskärmen project.

Another method of activity analysis which is basically was WSM (Work Sampling Method) has been adopted and tallied on Fallskärmen project as stated in the below section in details. This analysis was conducted as a practical methodology to detect the management gaps during a practice implementation through four site visits. Also, the same analysis was applied to establish an improvement strategy for the construction company as follows:

## 2.2 Carl Haas activity analysis of Work Sampling Method

Carl Haas model of Work Sampling technique method has been adopted to measure labourer's performance in reinforcement task. This technique was based on observing, collecting and recording the moments which contributes to loss of time. This technique was applied on Botrygg´s seven floor residential building project of Fallskärmen. Random observations on 10 reinforcement laborers during 4 working days that was a total of 32 hours of work has been observed on site and 25 observations per hour have been registered which are distributed across the entire work day.

The aim behind the application of activity analysis in Work Sampling method on Fallskärmen project was to find the proportion of unutilized construction time efficiently. As well to identify the non-value activities which have contributed into reducing the site labours effectiveness. The steps that could be followed in this method is described as below:

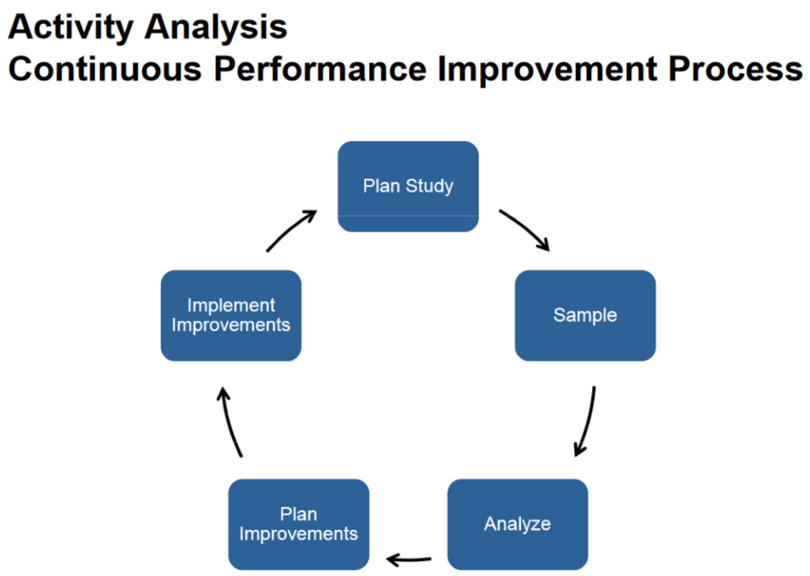


*Figure 2.1 Steps followed in the construction Activity Analysis in WSM*
*Source :(Haas, 2016), CII Construction Industry Institute,2017*

**The plan study:**

Authors of this research have observed the construction process of a specific case study. The observation collection process lasted for four working days. It started at 07:30 am in the morning and ended at 16:00 pm by observing 10 reinforcement concrete laborers working on reinforcement activity for a slab.

### 2.2.1 Sample Observing work behaviour

Observations have to be classified into the activity modes level which involved productive, semi-productive and non-productive. Those observations are specifically focus on the working crew who are currently involved in operation. The method activities were defined as sampling work by classifying them into three categories modes as below:(CII, 2017) (Hass, 2016)

*Table 2.1 Classification of observation into activity modes*
*Source: (Haas, 2016) & (CII, 2017).*

| **Classification** | **Productive** | **Semi-productive** | **Non-productive (No-working)** |
|---|---|---|---|
| Description | Fully produktive & direct work | Half productive as indirect work | Non contributing to any activity |

The tool that has been used for data registering was a table sheet as shown in the following:

*Table 2.2 Spreadsheet form to register data and observation based on activity modes Source: (Dozzi & AbdulRizk, 1993)*

| **Observation no** | **Productive (Direct work)** | **Semi-productive (support work)** | **Non-Productive (Delay)** |
|---|---|---|---|
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |
| **6** | | | |
| **7** | | | |
| **8** | | | |
| **9** | | | |
| **Total** | | | |
| **percentage** | | | |

All observations should be recorded on the form according to the appropriate mode of activity observed by check marking them. Breaks, lunch and clean up time is not included in the observation time. So, this time should be compensated if the data collected is inadequate for analysis (Haas, 2016).

### 2.2.2 The analysis of observations:

The amount of wasting time as non-productive or support are defined according to hourly based observation taking. This technique extracts a percentage of time the labour is productive and non-productive compared to the total time the person has spent in the operation (Haas, 2016). The observation taking were spread over the whole working day and the data registering for each activity should be limited and taken periodically.

### 2.2.3 Analysis Results:

The result which has been reached through observation gathering. The variation in utilizing the entire work day time for being both directly productive and versus non-productive between different activities were demonstrated in percentage converting system. Percentage ratio of both non-productive and direct productive work are described as follows:

The percentage allocation system was ranked according to their importance indexes with relation to their impact by shortlisting them in tables and shown through pie diagrams. Diversity of all activities that were responsible for upcoming the non-productive work as non-value-added activities were shown in staple diagrams. Each activity was provided a percentage share to highlight how much it has contributed into waste in work time.

### 2.2.4 Result´s Improvement plan

A management improvement plan has been recommended in improvement section based on the results concluded from the activity analysis. This plan contains an organized Work Breakdown Structure to assign right person for the right task. The WBS was constructed according to the gaps indicators and to mitigate the managerial defects and refill different gaps in management practice and take the immediate actions.

## 2.3 Limitations

The empirical study to measure project´s laborers productivity to figure out indexes for the on-value added activities in the reinforcement task were limited due to lack for data registry. This limitation as complicated the process to get access for abstract and clearly registered which contributed to task delays on construction site. As Botrygg does not invest much on its projects development and not conducting any evaluation process to its previous projects. Therefore, there was no statistical records related to non-valued activity indexes to show mistakes done and defects found. There was a limit to show the actual time duration for its overall tasks compared to the time frame has been dedicated and scheduled in the initial planning. The activity analysis of Work Sampling method was the only way to be adopted in Fallskärmen to find out how much construction time was utilized on reinforcement task on site due to information gaps. The only data which was relied on in measuring the reinforcement productivity benchmarking was the aggregated data of calculation spreadsheet form a for the case study previous projects.

Other limitation was the small size of the company and fewer number of its driven projects which somehow has made a narrower scope to cover just few projects instead of coving a wide scaled project area. In this study. Another limitation was variety of residential projects which framed between large projects of 16 stories and small one of 2 stories of apartment blocks. None of its projects are identical to others within size and investments. This has made the taken indexes would focus only on the reinforcement task in assessing what the value added, and non-value-added activities were. Same values were also measured only for reinforcement task during benchmarking of the case study projects. The reason was this specific task is a common repetitive task which has the same milestones and requirements in every project which can be a good foundation for a reasonable measurement. Those were some of the limitations which brought about difficulties in the study to obtain clear values from the management data base.

The site manager was not able to provide us reasons for the delays neither on Fallskärmen project nor in the previous projects that he had because the data were not task oriented. He did not provide any information about the laborers wages and salaries so as to make a deeper research about the project costs and engage in laborers hourly costs.

# 3 The Theory

This chapter provides us a picture of construction labour productivity and its implications on a construction project´s output. The chapter discuses two methods, one method emphasis on how labour productivity is measured by comparing with other projects productivity in a benchmarking measurement methodology. The other one argues an activity analysis technique about how much the workforce has been productive and given value to the production output. In this method researchers look at the labour productivity through the time utilization percentage model in producing construction units. Some others look at it through the value index model to estimate the resources of input invested with respect to the output gained from the project. A definition of the word labour productivity is also mentioned below

## 3.1 Definition of Labour productivity

Labour productivity has been defined by many research as performance factors, production rate, and unit of person per hour (p-h) (Enshassi, 2016, Dozzi & AbdulRizk, 1993, Josephson and Saukkoriipi, 2007). In this research labour productivity is described as the traditional term of a physical work which progresses in p-hours to achieve certain output. This term could be translated mathematically by the ratio of input resource /output production units (Dozzi & AbdulRizk, 1993 and Thomas, 1994).

Another definition, of labour productivity concerning construction industry refers to units of work produced per staff-hour which is an activity measuring dominated model of productivity (El-Ghory and Aziz, 2014). While Organization for Economic Co-operation and Development defines labour productivity as it is an amount of service a labourer produces in a given amount of time (OECD, 2002) “the ratio of a volume measure of output of GDP to a volume measure of input of work hours" (OECD, 2002).

The focus on labour productivity in this research was mainly on micro level which covers the management and operation on both the project and task-based levels. As such there was an inevitable need to search for researchers´ argument to look for how this productivity proceeds forward. Also, to look at what implications this productivity has in construction project´s progress about value and non-value-added activities. (Josephson and Saukkoriipi, 2007) have illustrated significant values of waste indexes which construction projects were suffered from on the firm level.

(Enshassi et, al., 2006) has also reported that there was a serious need to assess productivity variations within various projects by comparing their baseline productivity indicators between each other’s on the task level. This comparison aimed to show how much differences in production units were found which vary between those projects by applying Thomas and Zvarski theory of construction productivity benchmarking. This benchmarking was done to develop a standard and provide reference point to identify the future state for each firm which may lead to improvement in the project´s production (Enshassi, et al., 2006).

The first theory of Thomas and Zvarski model of project benchmarking productivity is argued in the following section in detail.

## 3.2 Benchmarking Projects Labour Productivity

It is a common metric to describe labour productivity (the ratio of work hours to units of output); and productivity factor (the ratio of schedule to actual work hours) (Couett et al, 2011). Benchmarking guides companies to improve their performance by establishing the best new performance practices (El-Mashaleh et al. 2007).
According to the construction Industry Institute CII for measuring the productivity a certain method has to be adopted by the project managers in determining the baseline for the best construction performance (CII, 2011). The model of Thomas and Zavrski was known as an international benchmarking of labour productivity according to (Enshassi, 2006). Their model is widely applied to compare labour productivity of one construction project to that of another (Enshassi, 2006). This comparison could be based on the man-hours employed to the work produced. It is measured and compared to past records of the same firm or other firm's data in order to obtain a baseline measurement about how efficient a firm has been in executing its activities according to (Thomas and Napolitan,1995; El-Mashaleh et al.,2001 and Enshassi et al, 2006). As (Enshassi et., al, 2006) mentions some advantages in adopting this theory as below:

### 3.2.1 Advantages & Objectives of benchmarking method

Measuring productivity at the firm level has many benefits for the project managers as supported by (Enshassi et al, 2006) as follows:

- It helps the management decisions to utilize resources across the project to obtain highest return and invest more in resources.
- Allows the contractor for better understanding their competitive positions and benchmark their efforts to improve their performance (Enshassi et al, 2006).
- According to (Thomas and Mathews, 1986) to measure productivity in benchmarking is to control project cost and schedule also to obtain data for planning future projects.
- To identify shortages and gaps in the project´s performance (Haas et al, 2017).

According to (Thomas, 2012) the labour productivity benchmarking study can be conducted by using three key performance indicators or attributes within productivity variability. Those indicators are baseline productivity, project performance ration and project waste index or project management index PMI which is a dimensionless measure for the amount of labour waste involved a specific activity or the entire project (Nirajan, 2015).

### 3.2.2 Baseline productivity definition

This attribute is the best performance the contractor can have under the project´s time span concerning the daily productivity values. It should comprise minimum 10 % of the total work days with the highest output registered out of 25 –40 % of the entire project (Randolph, 2015). This baseline productivity can be determined on the project level through the project´s data of the daily productivity values for each task. The number of workdays of the daily productivity should involve those days which have the highest daily quantity of square meters and they should not be less than five days.

It is the ratio of labour daily productivity in work hours(WHs)divided by the quantity of area produced in square meters(m2). The lowest this ratio is, the highest baseline productivity would be which indicates the best performance the contractor has achieved. (Enshassi et al., 2006).

### 3.2.3 Baseline productivity function

Baseline productivity is one of the most fundamental comparable attributes of bench marking measurement theory as Thomas and Zavrski concept model invented on 1999 and discussed in (Enshassi, 2006) article. At the micro-level, this baseline attribute measures the project´s labour productivity that could be compared with another completed and past project´s baseline attribute. This helps the site managers to establish a reference point to start improving the project´s output. It also identifies the variations in labour performance when the project deviates from its required productivity rate and assess whether its profitable or not. It also helps the contractor to find which project has the best performance through comparing it with another project´s baseline (Enshassi et al., 2006).

### 3.2.4 Measuring steps of baseline

The following steps show how to measure this baseline productivity.

- Determine the number of days that include minimum 10 % of the total work days of reporting period.
- Select (5) scores (n) of those days which have the highest quantity produced.
- Calculate the sum of all those daily work hours which have highest quantity divided by the size of the score (5) for each day which is the average baseline productivity(Randolph,2015).

This indicator or attribute can be measured through Equation no. **(1)** as below:

$$\boldsymbol{Unite\ rate} = \frac{\textbf{Input}}{\boldsymbol{Output}} = \frac{\boldsymbol{WHs}}{\boldsymbol{Unit\ of\ work}} \qquad \boldsymbol{equation}\ (\mathbf{1})$$

### 3.2.5 Other attributes

According to (Thomas, 2000) to predict the productivity rate of a completed activity more accurately other attributes should be determined such as the cumulative productivity. This index is the ratio of the final work hours charged to the total quantities have been performed. It is a measure to overall effort needed to finish the work which can be measured in equation no. **(2)** as below:

$$\boldsymbol{Cumulative\ Productivity} = \frac{\boldsymbol{Total\ work\ hours\ charged\ to\ a\ task}}{\boldsymbol{Total\ quantity\ installed}} \qquad \boldsymbol{equation}(\mathbf{2})$$

Next index is Performance ratio (PR) which is the actual cumulative productivity divided by the average values of baselines for all activities or projects. It could be noticed that all projects have PRs of >1, however, the PR with a value >1.0 does not represent a poorly performing project. While it´s a comparison against the best overall performance of the projects in the data set (Ghoddousi, 2014). The lower the PR is the better the project performance would be according to (Abdel-Hamid et al., 2004 and Enshassi et al, 2006). The higher the PR is the poor performance the project has (Ghoddousi, 2014). It can be measured as equation no**. (3):**

$$\boldsymbol{Performance\ Ratio = \frac{Cumulative\ Productivity}{average\ of\ baseline\ productivity}} \qquad \boldsymbol{equation(3)}$$

As (Nirajan, 2015) argues that it´s important to measure the project´s waste indicator so as to know the amount of labourer waste within a targeted activity. PMI project management index reflects the contribution of project management to the cumulative labour performance on the project. The lower PMI is, the better management leading role has on the overall project´s performance (Abdel-Hamid et al., 2004; Thomas and Zavrski, 1999a, b). PMI is dimensionless but it provides basis to define the causes of poor material, equipment, information flows and improper planning in project management. The higher PMI value is the more indication of sub-standard labour performance and poor management found (Manoliadis O., 2011). It can be expressed as equation no. (**4**) in following:

$$\boldsymbol{PMI = \frac{Cumulative\ productivity - baseline\ productivity}{baseline\ productivity}} \qquad \boldsymbol{equation(4)}$$

The variability in production units is necessary to be measured when comparing and assessing more than few project´s productivity because it is inevitable (Randolph, 2015). The objective of this comparison is to know how much productive and efficient the laborers were in executing certain task of a specific project in comparison with another project cases (Enshassi et al, 2006). High variability in productivity rate indicates that the project´s workforce has poorly performed when it´s compared with another well performed project which has no variation in labour productivity (Thomas & Sudhakumar, 2013).

## 3.3 Variation in Labour productivity

Variations in the WHs per week have been noticed in projects (Thomas, 2000). Also, many reasons as weather, design errors, accidents and decision changes would vary the inputs on a regular basis (Hanna et al. 1999a, b; Thomas and Napolitan, 1995). Input variations occur both in large and small projects, and in various geographical regions of a country. For example, if after the work start at 7:00 a heavy rain starts continuing to work would be impractical then the workers might be sent home early. This means if the work shift is 8 hours, the labour performance will suffer from shorter work shift according to (Thomasetal. 2002; Thomas and Horman, 2006). Similarly, if the work output (quantity)varies, the WHs should also vary. As variation in output is inevitable to encounter, so the input of work hours variability would be a direct reaction to output variability (Randolph, 2015). Implying operating and assigning the crew size should be consistent with the work available to be done and the only way this can be maintained is by varying the WHs according to (Randolph, 2015). Enshassi has explored a study of measuring labour productivity in masonry of stonework case within nine projects to demonstrate how the daily variations in productivity is proceeding. Many project attributes have contributed to vary in project's output and functioned in this variation as follows:

### 3.3.1 case study 1

In Gaza strip data were collected for Noor El-Maref school building project to measure the labour productivity for masonry works where the data included the workforce size, daily working hours and the daily quantity output (Enshassi, et al., 2006). The following table is data from only Noor El-Maref school as a single project just to define how measuring of baseline productivity attribute model functions as below:

*Table 3.1 baseline productivity indexes of Noor El-Maref project in Gaza Strip*

*Source (Enshassi, et al., 2006)*

| Day | Crew size | Workhours (hr) | Daily qty ($m^2$) | Labor daily prod. (whr/$m^2$) | Baseline days |
|---|---|---|---|---|---|
| 1 | 2 | 16 | 27.53 | 0.5812 | |
| 2 | 2 | 18 | 31.62 | 0.5693 | |
| 3 | 4 | 36 | 95.44 | 0.3772 | * |
| 4 | 6 | 48 | 128.7 | 0.3730 | * |
| 5 | 5 | 45 | 94.31 | 0.4771 | |
| 6 | 5 | 45 | 96.22 | 0.4677 | |
| 7 | 6 | 48 | 120.92 | 0.3970 | * |
| 8 | 5 | 40 | 116.31 | 0.3439 | * |
| 9 | 5 | 44 | 79.56 | 0.5530 | |
| 10 | 5 | 40 | 71.31 | 0.5609 | |
| 11 | 4 | 32 | 78.92 | 0.4055 | * |
| 12 | 4 | 36 | 51.91 | 0.6935 | |
| 13 | 5 | 40 | 60.2 | 0.6645 | |
| 14 | 4 | 32 | 46.02 | 0.6953 | |
| 15 | 2 | 16 | 34.96 | 0.4577 | |
| 16 | 3 | 24 | 46.4 | 0.5172 | |
| 17 | 2 | 16 | 28.79 | 0.5557 | |
| 18 | 2 | 14 | 19.89 | 0.7039 | |
| Sum | | 590 | 1,229.01 | 0.4801 | |

To demonstrate the baseline productivity index, the best scores marked by (*) of the daily labours productivity which are the five lowest measured values are found as 0.3772, 0.3730, 0.3970, 0.3439 and 0.4055 whr/m2 in the above table. Accordingly, the baseline productivity for Noor El Maaref would be the summation of all daily labour productivity divided by five which is the average of those five values as equals 0.3793 whr/m2 (Enshassi, et al.,2006) as shown in the diagram below:

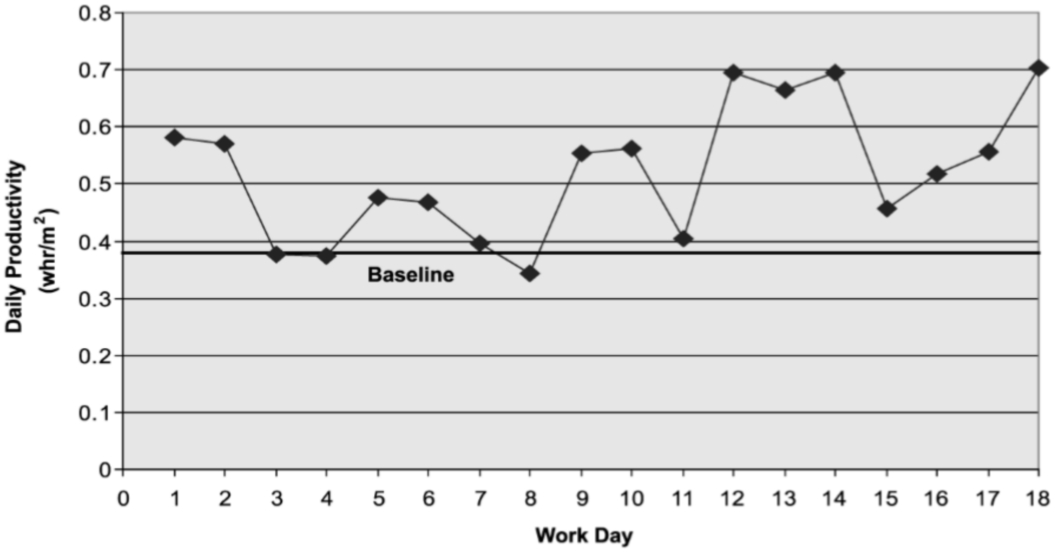


*Figure 3.1 Baseline productivity diagram of Noor El-Maref project in Gaza Strip Source:( Enshassi, et al, 2006)*

The highest whr/m2 index value indicates the worst baseline daily productivity the project task has experienced. The lowest index value of whr/m2 shows the best baseline productivity the project has achieved according to Thomas and Svarski theory mentioned by (Enshassi, et al., 2006).The baseline productivities from nine different projects of residential, office, parking and school buildings in Gaza Strip have been compared together to decide which one has the minimum productivity as shown in this table below:

*Table 3.2 The baseline productivity of nine projects in Gaza Strip*

*Source:( Enshassi, et al, 2006)*

| Project no. | Cumulative prod. (whr/m$^2$) | Baseline prod. (whr/m$^2$) | Project management index (PMI) |
|---|---|---|---|
| 1 | 0.4801 | 0.3793 | 0.2119 |
| 2 | 0.3461 | 0.3012 | 0.0943 |
| 3 | 1.1782 | 0.8012 | 0.7928 |
| 4 | 0.4809 | 0.4332 | 0.1002 |
| 5 | 1.0022 | 0.7110 | 0.6124 |
| 6 | 0.6350 | 0.4431 | 0.4036 |
| 7 | 0.7019 | 0.5882 | 0.2392 |
| 8 | 0.3453 | 0.2910 | 0.1143 |
| 9 | 0.3964 | 0.3312 | 0.1370 |

Project no. (**2**) has the best productivity with regard to the best management leading role on the project´s overall performance due to having the lowest index of PMI and baseline productivity of wh/m2 among the rest of projects. While project no. **(3**) has the worst productivity level and poor management due to its highest index for the same type of project´s attributes.

All the above indexes were studied by Enshassi targeted a specific masonry task for all Gaza Strip projects which presented a remarkable variation in their productivity during different time periods. While a deeper and more detailed study was made by (Josephson and Saukkoriipi, 2007) which covered only one single project to explore minutely based observation taking. The observation was taken from different and multiple tasks for the individual workers as mentioned in case study no 2 below. The study showed statistical indexes of how many working minutes there were for being the most effective moments in adding value on construction than other minutes during the whole day.

### 3.3.2 **Case study 2**

The typical work day contains many interruptions for the project manager as disturbance and changes of work tasks. This could be breaking up of work which involves other workers as subcontractors. While this interruption does not include coffee break and lunch. In an eight-hour work day at a construction site, task changing within two minutes interval is a great issue to break up and interrupt their work. laborers changed their tasks and variated duties 156 times during the work day as shown in figure no (3.2) by observation taking every second minute. The changes involved certain activities of material handling (code 31) and moving (code 57) between different places for 28 times during the day. The work which adds value (code 11-13) took only ten minutes on only 32 occasions (Josephson and Saukkoriipi, 2007)

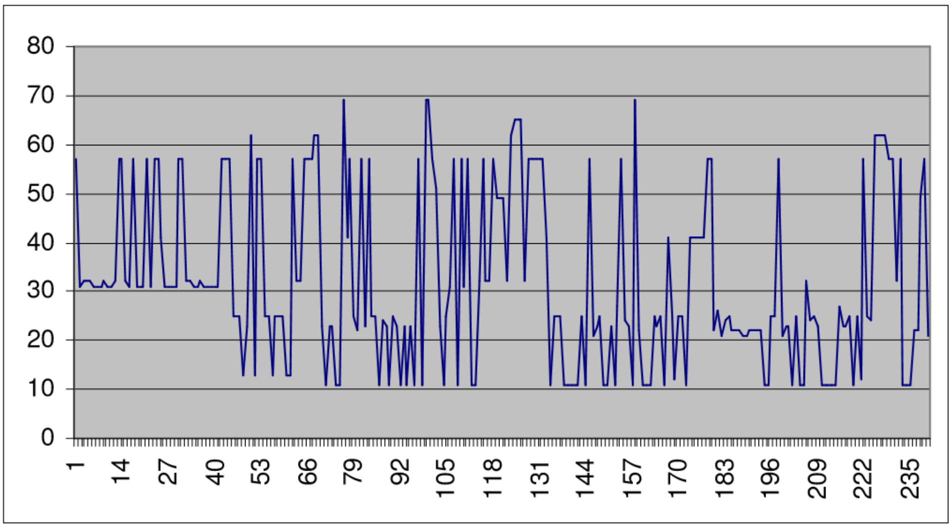


*Figure 3.2* Observations taking every two minutes during eight-hour work day
*Source: (Josephson and Saukkoriipi,2007)*

The horizontal axis shows the number of minutes during the day time and the vertical axis is the code number of involved activities. (11-19 codes were activities that added value, (21-49 codes were preparation activities and 51 –79 codes were non-value-added activities (Josephson and Saukkoriipi, 2007). Obviously, the non-valued activity codes result in a lower rate of labour productivity and the valued activities lead to the targeted level of labour productivity. As such the work day consisted of only 9 codes from code no 11 to 19 for the value-added activities has made the individuals effectiveness become very low. While existing of many non-valued activities of 28 codes from code no 51 to 79 have resulted in too much waste in working hours during the work day. The project has experienced this waste because of frequent switching between different activities from time to time and prioritizing some on others during the work day (Josephson and Saukkoriipi, 2007). Accordingly, the result was a high variation and fluctuation in the rate of labour productivity due to task swapping and substituting between different site activities.

It´s worthwhile that both Enshassi and Josephson looking at the productivity subject through different perspectives. Enshassi´s perspective looking at the point through the trend of utilizing working hours to produce amount of area square meters (Wh /$m^2$). This metric system illuminated the issue and weakness of labour productivity as case study 1 on the project level for multiple projects. While Josephson & Saukkoriipi looked at individuals' timely effectiveness and types of activities which add value versus do not add any values on construction during the work day as case study 2. Whereas each one of these two perspectives refer to the same concept of variation in project´s labour productivity. Both these two trends have their own measuring tools and approaches for being estimated. Enshassi has adopted the benchmarking method for productivity evaluation while Josephson et al have adopted timely or minutely observation taking to measure the workforce´s effectiveness. This model highlights the shortcoming found during activities execution. Another study which was conducted by Josephson in the following case study no **(3)** to show different shares of wastes which did not add any values on the entire project tasks.

### 3.3.3 **Case study 3**

The focus should be on the individual labourers to see what they do to understand how much work was devoted to adding value on construction. An example was taken to observe a group of laborers for construction of new homes during 22 work days. The observation was taken to all over tasks for the entire project. Work time was divided into three parts. The first part was the work that directly increased value was 17.5 % of the total work time in the targeted project as explained in figure no (3.3) by (Josephson and Saukkoriipi, 2007).
The second part was preparation which includes activities to produce but do not increase any value to the project. This part was estimated as 45.4 % of the work time which includes preparation work as handling of equipment and material. Material and equipment preparation was 25 % out of the whole proportion while 14 % was spend for material transport and movement with 6 % for the planning work (Josephson and Saukkoriipi, 2007)
The third part was waste in working time which was estimated as 33.4 % which has neither any effects nor adding value on construction. This part includes reworking, waiting for materials and work interruption. 23 % was due to waiting and moving between different workplaces while 10 % was for unutilized due to moving to and from the cabins (Josephson and Saukkoriipi, 2007). The distributed shares of value added, and non-value-added works is presented as below:

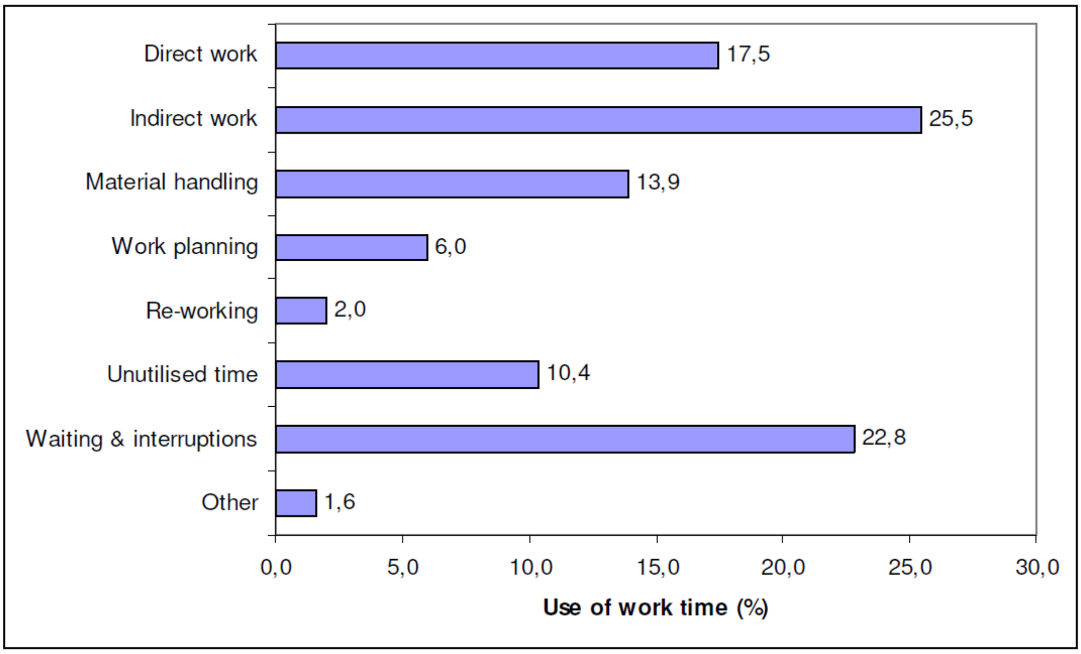


*Figure 3.3 Percentage shares of value and non-value-added activities of work time*

*Source: (Josephson and Saukkoriipi, 2007)*

This result showed a low proportion of work that increases value to the construction. The work that was done by the construction laborers which directly added value estimated as 16.4 % if the sick laborers would have been included in this result. It was seen that effectiveness of individuals was about 13.4 % of the total time on site . This means seven laborers were needed to carry out the work for one person in order to add value on the project. This approach can clearly draw a boundary between what is valuable and not valuable for the project (Josephson and Saukkoriipi, 2007)
Other studies have been done in Sweden for the plumbers and sub-contractors with the same size of construction workers resulted in the same amount of waste. If assumptions show that 33 % of working time is wasted by the laborers this would correspond to 5 % of the whole project´s cost (Josephson and Saukkoriipi, 2007).

The types of waste in those projects were classified into three processes as:

- Operative work process that directly add value to construction in the view of the client where the activities could be executed in another order to save and speed up the construction time.
- Support process includes monotonous activities as preparation for value adding work which are necessary for the operation.
- Management process includes activities that aim to determine the organization´s strategies which do not add direct value to the productivity rate and absorbs resource. Examples of this one could be rework, waiting time, transport of materials, walking around without doing work and storing material that wait to be handled (Josephsson & Saukkoripii, 2006)

According to Josephson and Saukkoriipi above indications, there was a large amount of variation between what was really productive and what was devoted to be non-productive work. The steps to resist this large variation rate were to correct the defects and gaps which might impede the way into better improvements. To achieve this, aim the focus should be on eliminating the waste and make the preparation more effective to increase the value-adding works according to (Josephsson & Saukoriipii, 2009).

However, the benchmarking metric method was only aiming to measure productivity on a project level. Therefore, this method cannot analyse those shortages occurred during executing project´s task elements according to (Thomas &Zvarski, 1999). This benchmarking model is just a tool to identify the variations in the labourer's daily productivity and provides a better understanding on how to improve using the resources. Therefore, there is a need to find another functional and practical mechanism system to analyse the workforce´s practice implementation. Therefore, the workforce´s work sampling should be measured and analysed on the activity level in order to define the gaps that exist in practice elements which need improvements (Haas et al, 2017).

As response to this variation, improvement strategies should be implemented by companies to optimize the productivity font. (Haas et al, 2017) framed in these improvements in three management levels (crew, project and corporate). At the crew level, productivity improvement focuses on a higher direct work rate by reducing the non-productive work time portion in the total worktime. Direct work rate is defined as the ratio of the direct work hours over the total work time. This metrics determines the productivity within the crew activity level(Haas et al, 2017).

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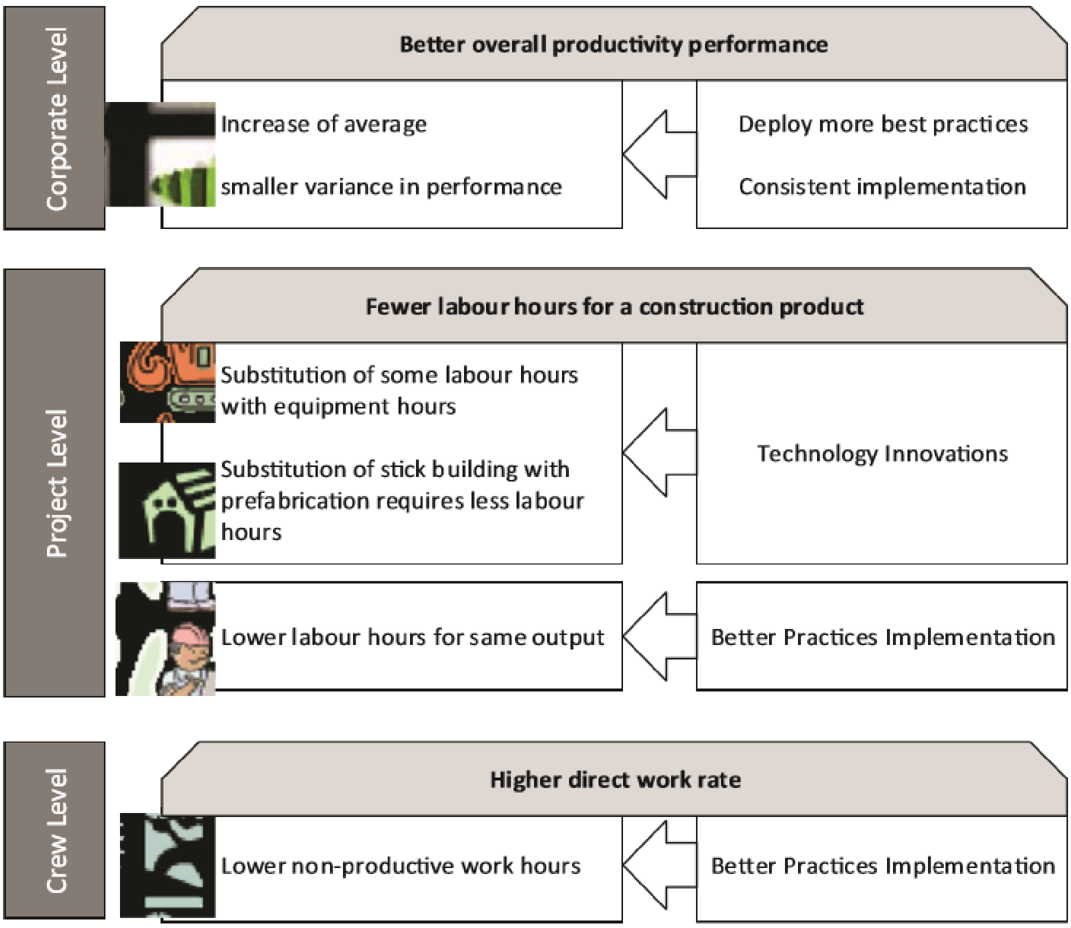


*Figure 3.4 Construction labour productivity improvement framework*
*Source. (Haas et al, 2017)*

As productivity is one of the performance elements in metric system of benchmarking model, therefore it relies on the information of solid data which is representing the current situation of practices implementation in projects. The data collection depends on the existing of a progressive construction work which should comply with the aggregation of direct work rate according to (Haas et al, 2017) The performance metric system consists of the direct work rate and cumulative labour productivity formula as below:

$$Direct\ work\ rate = \frac{Observation\ of\ direct\ work}{Total\ number\ of\ observations}$$

$$Cumulative\ labor\ productivity = \frac{Work\ hours}{Unit\ of\ physical\ output}$$

Certain performance metrics are used to measure the productivity level of the specific project on workforce level and identify the direct work, cost and schedule changes. The focus is more related to the site crew level where there is no workface assessment method exists to identify productivity inhibitors affecting site labour. Therefore, in response to this gap, there was a need to develop a workface assessment method called activity analysis. This analysis is the tool used for improving direct work rate by adjusting activities appropriately (Gouett et al, 2011).

This analysis includes measuring the current state of practices implementation and determining what steps need to be taken to improve those practices from its current state. (Haas et al, 2017). This activity analysis determines correlation between both the productivity and direct work rate. It analyses the impacting factors of indirect work rate with respect to environment and statistical analysis. It introduces multiple gap factors for each practice element, those factors respectively represent the improvement room to the best-in-class (Haas et al, 2017, Gouett et al, 2011)

It is an improvement tool which efficiently measures the time expenditure of workers on-site. It identifies the inhibitors that management must eliminate to provide workers with more time for direct-work activities. It is the assessment of direct work rate which reflects the productivity level and time proportion that workers have dedicated to specific work activities. It´s the extension of a work sampling technique into a continuous improvement process (Gouett et al. 2011, Kirsi, 2015) as explained below:

## 3.4 Sample Work Method Technique

The metrices measured using work sampling with the limitation in mind were direct work. This technique involves periodical observations on workers, machines and equipment to analyse tasks. This method can be applied both on a single ongoing task only and also on many tasks which are ongoing concurrently at the same time (Haas et al. 2017).

(Dozzi & AbouRizk, 1993 and Haas, 2016). Work Sampling Method Technique is the existing method adopted by Carl Haas as explained below:
This method was developed in 1930s as a Statistical basis i.e. a sample of multiple random data points where the accuracy was dependent upon number of samples taken. Observations were taken randomly for workers involved in a delegated operation on site which should indicate the workers' activity mode if they were in a productive, non-productive or semi-productive mode (Dozzi and AbouRizk, 1993). This method was carried out through employing site observers. To achieve methods objective the project´s activities should be classified into mode categories as below (Dozzi and AbouRizk, 1993):

**Example for activity classification parameters criteria**

*Table 3.3 Work Sampling Technique classification parameters and criteria's Source: (Dozzi and AbouRizk, 1993)*

| **Classification**<br><br>**(equivalent classification)** | **Productive**<br><br>**(direct working)** | **Semi-productive**<br><br>**(Indirect work support** | **Non-productive**<br><br>**No-working)** |
|---|---|---|---|
| Description | Using trade tools | Supporting the main activity | Non contributing to any activity |
| Examples | Mason laying bricks, laborer mixing mortar, electrician pulling wire, welder welding pipe | Material movement, getting material, traveling to work location, taking instructions | Personal breaks, waiting for equipment to be fixed, waiting for more instructions, late start and early departure |

The resulting percentage could be figured out through converting the person hours into percentage quota. (Dozzi and AbouRizk, 1993). Adding up all the checkmarks under each mode and calculate the percentage of activity. Then the percent could be measured as 4/9 (= 45%)for the productive, 3/9 (= 33%) for non-productive and the balance of 22% would go to semi-productive.

*Table 3.4 Work Sampling Sheet of percentage rate to the individual labour performance Source: (Dozzi, AbouRizk,1993)*

**Work Sampling Sheet**

Project:

Date: Observer:

Notes:

| Observation No. | Productive (Direct work) | Semi-Productive (Support work) | Non-Productive (Delay) |
|---|---|---|---|
| 1 | √ | | |
| 2 | | √ | |
| 3 | √ | | |
| 4 | | | √ |
| 5 | | | √ |
| 6 | | | √ |
| 7 | | √ | |
| 8 | √ | | |
| 9 | √ | | |
| Total | 4 | 2 | 3 |
| Percentage | 45% | 22% | 33% |

The observer must make a large number of observations estimated about minimum 46 per hours with respect to the size and of the project and the number of ongoing tasks concurrently or a single ongoing task. This is to determine more observations and to collect accurate statistical data sample taking (Haas, 2016). This number derives a 5% error and a level of confidence of 95% which means a high rate of accuracy. Every glance at site is regarded to be as an observation (Dozzi and AbouRizk, 1993).

**Method Objective**

The main purpose of this method was to observe the construction work for a limited time by taking observations on site. Those observations extract the performance of operation in which the labour productivity was the major part of it (Kisi, 2015).
According to Kisi work sampling has three main objectives as:

- First: determines how much time was utilized by the workforce and the cause of delay time area (Kirsi, 2015).
- Second: draw more intensive management attention towards the most affected tasks that were subjected to delay and poor labour productivity.
- Third: establishing a plan for labour productivity improvement (Kirsi, 2015).

The advantages of WSM are simple procedure with quickly obtaining the unbiased results after finishing the study. It can be interrupted at any time without affecting the result. Also, it´s less time-consuming and it is economical. (Kirsi, 2015). According to (Kirsi, 2015) understanding of the affecting factors which have caused poor labour productivity could be a success factor for the construction managers to achieve a cost-effective project in timely manner. Implying, there is a link between factors and productivity through measuring their impacts on productivity (Herbsman and Ellis, 1990; Thomas's et al., 1990). As such applying this method of WSM would determine the factors impacting on lower productivity which cover the entire project´s tasks or a specific targeted task as mentioned following:

## 3.5 General Impacting Factors on Labour Productivity

Classification of those factors into categories is easiest way of managing them (El-Ghory and Aziz, 2014). The impacting factors are classified into management, technological, human and external factors as below (Jarkas and Bitar, 2012). The perceived effects of all those factors could be framed within four major effective groups as follows:

*Table 3.5 Groupings of labour productivity affecting factors*
*Source: (Jarkas and Bitar, 2012)*

| Group | Average Relative Importance Index (%) | Rank |
|---|---|---|
| Technological | 70.69 | 1 |
| Human/labour | 60.54 | 2 |
| Management | 54.91 | 3 |
| External | 54.05 | 4 |

### 3.5.1 Management Factors

Insufficient managerial approaches to minimize waste would increase unnecessary working hours and reduce the project´s output. It is unwise to invest resources of material, capital, energy, labour and equipment with mismanagement practice in place (El-Ghory and Aziz, 2014).

**Lack of supervision** could encourage operatives to involve in unproductive activities such as taking frequent unscheduled breaks, sitting idle, waiting, or even abandon the site during working hours to attend personal matters (Jarkas, 2014).

**Working overtime** causes physical fatigue to operatives and decreases their agility, and motor skills. It does not even only lead to lower productivity, but results in a high probability of poor workmanship, rework, and deteriorates the site safety condition (Jarklas, 2014).

**Schedule compression and acceleration** to reduce the project´s time span not only negatively impacts the efficiency but also becomes a source of dispute between employers and contractors (Jarkas, 2014).

**Site congestion** is mainly caused either by mismanagement and planning defects of the work sequence or by increasing the number of operations. For example, overmanning, to speed up the work of a certain activity is expected as a negative impact because there is an evidence of labour density greater than one person per 30 m2 would lead to decrease in labour efficiency (Naoum, 2016).

(Jarkas and Bitar, 2012) have related the management factors with relative importance index and ranked them based on a survey study which has been conducted on the affecting factors as shortlisted in the next page:

*Table 3.6 Relative indexes of labour productivity affecting factors*
*Source: (Jarkas, 2012)*

| Factors | Relative importance index (%) | Rank |
|---|---|---|
| Lack of labour supervision | 81.67 | 1 |
| Proportion of work subcontracted | 80.64 | 2 |
| Lack of incentive | 78.60 | 3 |
| Construction manager´s lack of leadership | 77.71 | 4 |
| Unsuitability of storage area position | 67.64 | 5 |
| Composition and size of the crew | 55.41 | 7 |
| Inappropriate scheduling | 55.13 | 8 |
| Labour site congestion | 54.65 | 9 |
| Shortage of material (supply chain mismanagement) | 52.87 | 10 |
| Construction method | 52.44 | 11 |
| Payment delay | 52.36 | 12 |
| Communication issue between management and labour | 52.10 | 13 |
| Accident due to poor site safety program | 51.59 | 14 |
| Late arrival, early quit, unscheduled breaks | 50.57 | 15 |
| Unavailability of tools | 50.45 | 16 |
| lack of training | 49.81 | 17 |
| Inspection delay by site manager | 49.04 | 18 |
| Sequencing problems | 43.85 | 19 |
| Lack of recognition program | 43.74 | 20 |
| Lack of periodical meeting with the foreman | 43.44 | 21 |
| Clients intervention with management | 37.96 | 22 |
| Lack of suitable area offered to labours | 36.18 | 23 |

### 3.5.2 Technology & Innovation Factors

**Design complexity** with incomplete and mysterious technical specifications requires continuous requests for information (RFI) which slow down the building process. This complexity causes consecutive interruptions due to revisions to modify and match the design documents with the site layout. This results into too much site reworks and reduction of site productivity. Accordingly, an early form of relationship between the designers and contractor should be established (CII, 2017).

**Lack of cohesion and engagement** between the two disciplines of construction and design contributes to inability for looking at the whole construction process through each other's perspectives. Therefore, the design compatibility to specific site characteristics and layout has a direct influence on the construction productivity (Jarkas and Bitar, 2012). Jarkas and Bitar have ranked the technical factors as follows:

*Table 3.7 Relative Indices and Ranks of Technological Group Productivity Factors Source: (Jarkas and Bitar, 2012)*

| Factor | Relative importance index | Rank |
|---|---|---|
| Clarity of technical specification in design drawings | 84.33 | 1 |
| Change orders during execution | 83.69 | 2 |
| Coordination between design disciplines | 82.55 | 3 |
| Design complexity level | 79.62 | 4 |
| Intensive inspection by engineers | 77.07 | 5 |
| Delay in responding to request for information | 76.69 | 6 |
| Consistency among contract documents | 71.08 | 7 |
| Rework | 66.88 | 8 |
| Site restricted access | 63.95 | 9 |
| Working space | 60.64 | 10 |
| Site layout | 51.46 | 11 |
| Inspection delay from engineer | 50.32 | 12 |

The previous affecting factors argued by researchers were regarded as general factors that cover all stages and involve different phases in project´s construction process. Meanwhile some others classified those factors between two different stages as pre-construction and during construction stage as following:

## 3.6 Impacting Factors in Preconstruction Stage

Well-organized of the planning schedule prior to the project kick-off has been identified as one of the most important factors responsible to deliver a successful labour performance (Laufer and Tucker 1987; Douglas 2004). Buildability of the design attributes could have significant impact on labour productivity (Mydin et al, 2011). Furthermore, construction industry experts believed that the earlier the planning is performed, the larger is the positive impact it would have on the project´s output (Gibson et al. 1995). While the site managers have slightly different condition to adapt their roles in the pre-construction and planning stage depending on the contract type selected by the client (Andersson & Rosenberg, 2012).

### 3.6.1 Preconstruction Planning

During planning, the planners and managers make various assumptions with respect to executing construction activities, availability of resources, and adaptability of construction methods. However, not all of those assumptions are explicitly documented and verified before the construction activities starts. Decisions made about the planning´s execution and resources with workability of the construction method should be based on reality and verification of assumptions. Any defect in the project`s planning errors would be the most crucial factor influencing productivity (Naoum, 2016)

### 3.6.2 Design management

There are many contract types in the Swedish construction industry and the main difference between the contract forms involves dealing with the distribution of responsibilities between project´s stakeholders (Söderberg, 2011). Documents that include project description and drawings are reviewed in this stage, therefore those documents should support the contractor's ability to enhance buildability of the design (Andersson & Rosenberg, 2012).

Labour productivity starts since the project´s design phase but if the design contains complicated attributes, this defect needs direct on--site solutions by the contractor in coordination with the designers to produce a buildable site layout (Proverbs et al, 2010). The labour productivity can involve any stage of construction work starts from procurement of the design phase and the pre-construction phase. Since the design phase is regarded as an initial phase any complex in designs due to misunderstanding the full extent of site work can lead to difficulties for the contractor (Naoum, 2016). Designers and quantity surveyors do not have a full understanding about how the contractor utilizes the most optimal approach to get advantage of resources in terms of cost and speed according to (Hackett et.al, 2007).

There is a short time available between the design start up and the call for tender. As a result of that, tender documents are most often incomplete, unclear, or contain serious conflicts among the various disciplines (Jarkas, 2012). Waste time on site could be reduced if minimum design changes occurred on site due to the unreclaimable design errors (Naoum, 2015). To certify this trend El-Gohary and Aziz have stated that 50 % of waste for disposal sites in UK is produced from the construction waste has caused due to design incompatibility (El-Gohary and Aziz, 2014). Hence a complex design effects on the productivity rate and results into inefficiency due to incompatibility of the design to the site condition. As such design needs rationalization, mechanization and prefabrication in order to increase productivity (Naoum, 2016).

### 3.6.3 Buildability

Buildability in U.S. is known as constructability. Its defined as an optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall objectives. Proper and timely consideration of buildability will ensure that the final design will meet all the performance criteria that have been set for. This outcome saves the wasteful efforts and increases the production efficiency. According to (Mydin et al, 2011) the buildability increases the construction work efficiency by integrating and adapting this process with the designs attributes.

According to (CIRIA, 2016) Construction Industry Research & Information Association the buildability is known as the extent where the design contributes for an easier construction. When the buildability is considered sufficiently at design stage, then proper planning becomes more important (Proverbs et al, 2012). The design simplification can be achieved through the implementation of buildability principles as: 1) rationalization (2) standardization (3) repetition of elements according to (Jarkas and Bitar, 2012). The design rationalization is defined as "the minimization of the number of materials, size, and components. Whereas standardization is making the design product to be producible from those materials, components are remaining after design rationalization has taken place. At the same time the clarity, legibility and detailing levels of both design and fabrication drawings enhancing the design influences on productivity to proceed the construction´s operations (Jarkas and Bitar, 2012).

Buildability must be considered from the first notional idea of feasibility studies as a prerequisite throughout the overall project´s stages. It influences on the project costs and its value for money from early stages according to the client's viewpoint. This can be achieved through inclusion of different attributes for each stage since the conceptual planning until the use phase and facility management according to (Mydin et al., 2011) the figure below:

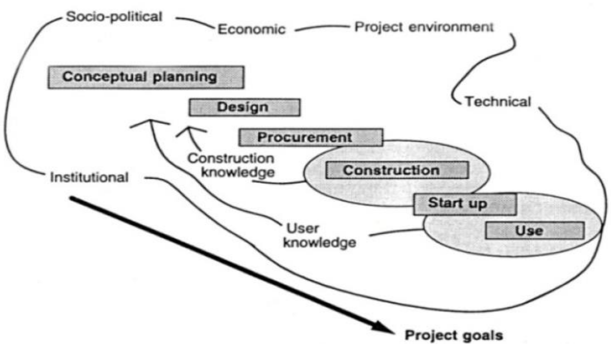


*Figure 3.5 Buildability framework figure*
*Source:( Mydin et al, 2011)*

As the design´s process has a major impact on the construction costs. As such the probability of project cost reduction during the feasibility studies has a high effect on minimizing the construction costs. Probability for cost reduction due to design changes during the construction phase is also minimum as shown in the diagram below figure 3.6. Therefore, waste minimizing should be taken into considerations according to (prolog, 2016).

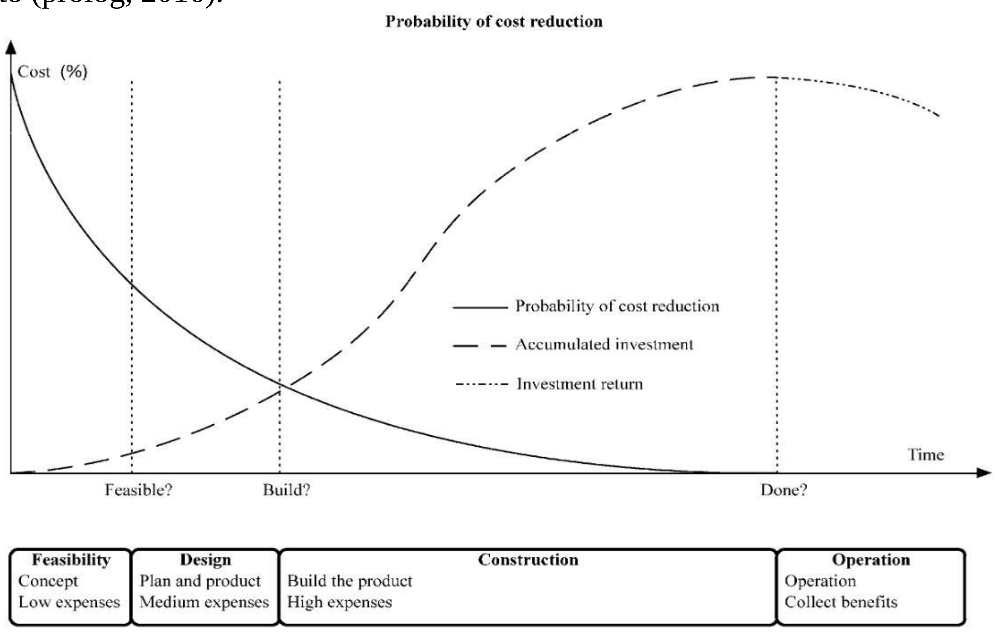


*Figure 3.6 design influence on construction cost reduction*
*Source: www.prolog.se (Prolog, 2016)*

## 3.7 Impacting Factors in Construction Stage

Productivity at the task level can be measured by quantifying of multiple factors such as the amount of work, crew size, constructability and environmental conditions (Proverbs et al, 2010 and Huang, et al, 2009). Although those factors may have similar impacts on productivity, their level of effects differ from one task to another. For example, renovations of an existing building have a lower productivity rate due to congestion and limited availability of space for work and labour movement (Yi & Chan, 2014)

According to Jarkas and Bitar productivity rate has been examined on different construction methods by comparing concrete against steel structure. The result showed that there are four factors that affect efficiency of concreting operation. Those are concrete workability, reinforcement steel congestion, volume of casting and the height issue compared to ground level considering the pumped casting method (Jarkas, 2012). Another UK model by (Proverbs et al, 2010) argues that other factors could have direct impacts on this rate as following:

- Transportation methods
- Scaffolding systems
- Formwork solutions to columns, beams or slabs
- Reinforcement fabrication
- Working time per day and per week by the workforce
- Allocated official break/relaxation time per day
- Number of days worked each week
- Numbers of onsite supervisors/ managers
- Numbers of unskilled, semi-skilled and skilled laborers (Proverbs et al, 2010)

### 3.7.1 Material Management & Supply Chain

Inefficient material distribution, different handling and inappropriate material management will obstruct the access both for laborers and materials as reported by (El-Gohary and Aziz, 2014). Therefore, stock and movement of materials is the most information item in the last planner approach in construction planning (Nauom, 2015). As (El-Gohary and aziz, 2014) have graded that availability and their ease of handling with easier access for materials to the contemporary task is ranked as second within the management group.

### 3.7.2 Site Asset Management

Productivity is highly related to the company´s policy of selecting type, quality and number of equipment and machinery are used. This relation found that activities that experiencing significant changes in equipment innovation have showed a greater long-term improvement in labour productivity. Proper managing the site assets` service also could be one of the factors to improve and provide sustainable tools for the laborers to ease performing their task (Naoum, 2015).

### 3.7.3 Congestion & Overcrowding

Overcrowding of a construction site is a normal characteristic for unorganized site arrangement which indicates inappropriate activity planning of the site (Jarkas, 2012). Since the scope area for working space is acceptable for free movement between 30 m 2 to 10 m 2 as a standard per one labour, any other density greater than 30m2 would restrict free movement. This results into decreasing of productivity (El-Gohary and Cottrel, 2006).

### 3.7.4 Knowledge management

According to Hislop, Knowledge can be defined as facts and data that can be transferred, received or acquired by individual to improve work efficiency in a positive manner. This knowledge is acquired socially and instilled into practice and experience in people (Hislop, 2013). Knowledge is dynamic in construction sector as all actors and organizations changes through time. Knowledge management is vital for future competitive strategies. Knowledge handling in construction project is crucial in interpreting futurity of the construction sectors (Koch, 2001).

### 3.7.5 Management & Leadership

Participative leadership behaviour determines the job satisfaction and efficient management skills can yield potential savings in time and cost. Whereas unstable and change in leadership has created a negative impact on obtaining contingent rewards for the work output agreed upon. Interpersonal relationship, possibility for assigning responsibility, advancement and wellbeing can have a positive output through increasing the labour work according to (Nauom, 2015). A good leadership increases the productivity through decreasing production costs, reducing time required for the operation and increasing profit with the utilization of resources (Abd-El-Hamied , 2014 & Jimoh et al, 2017).

### 3.7.6 Job Satisfaction & Motivation

Money, good supervision, security, working condition and interpersonal relationship will hinder dissatisfaction which prevents collapse in the labourers´ performance. Possibility for assigning responsibility, advancement and wellbeing can stimulate better work motivation according to (Nauom, 2015). Motivation is a driving force for the workers to achieve the firm´s objectives of a higher productivity rate (Jarkas & Radosavljevic, 2013).

As such all the above impacting factors on the labour performance would arise the need to establish an improvement strategy to enhance the projects´ productivity level. The cycle for productivity improvement involves four phases: productivity measurement, productivity evaluation, productivity planning and productivity improvement. This was the way that construction supervisors can improve how smooth and easy the work flow can be achieved (Abs-el-Hamied, 2014). The construction firms need to establish an effective system to find ways to produce more units with fewer resources (Haas et al,2017). (Haas et al. 2017) has argued in details the improvement framework on the firm level previously in figure (3.4). The project level improvement is cleaved and shown in the following section as below:

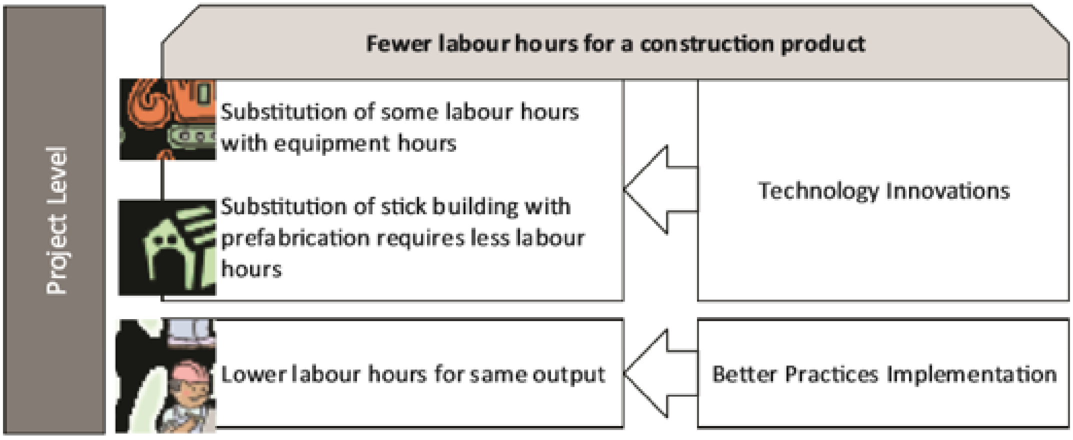


*Figure 3.7 Construction labour productivity improvement framework project level Source. (Haas et al, 2017)*

## 3.8 Labour Productivity Improvements

Those improvements can involve many practices on the project level. Labour productivity improvement could be implemented through technological innovations by substituting stick building with prefabricated elements. Also, practicing a better innovation is substituting labour hours with using machinery. These improvements require significant resources and upfront investment costs (Haas et al., 2017). This theory of Haas covers both the management and technological improvement trends as argued in the below section:

### 3.8.1 Off-site Production Model

The off-site production of building components is more productive than built on-site activities in USA even their rate of productivity growth is much higher than on-site. Off-site production means building with elements that are already pre-assembled from the factory and On-site means the elements will be built directly on the site. As an example, Off-site productivity grew 2.32 % annually while on-site productivity grew 1.43 %, therefore prefabrication is highly recommended (Eastman and Sacks, 2008 and Ghosh, 2015). Prefabrication, modularization and off-site fabrication (Eastman & Sacks, 2008; Huang et al., 2009; Mikhail, 2014). It was found that because of there are several hinders in adopting pre-planning, project coordination and transportation difficulties therefore adopting pre-assembly as prefabrication offers benefits of improving labour productivity and reducing costs (Ghosh, 2015 & Haas et al. 2000). Methods proposed for improvement are either through controlling the mistakes that cause poor productivity which could be better management strategies and technology innovations. (Thomas, Horman Jr, & Chen, 2003).

### 3.8.2 Management Strategies

Reliable labour-flows and labour management can be implemented through addressing issues such as, insufficient work to perform and overstaffing. A predictable work-flow should exist in order to match the available workload. (Liu et al., 2011) (Thomas, Horman Jr, & Chen, 2003). Integrated project delivery (IPD) method is a concurrent strategy to adopt for better collaborative work processes, lesser design changes, less number of request for information RFI's, and reduced RFI processing time (Asmar, 2012).

### 3.8.3 Technology Innovations

Technology innovation which brings new techniques speeds up the building process and improve labouring efficiency. Therefore, this innovation is essential to be included in the organizations construction industry´s policy (Naoum, 2015). According to Yi and Chan material and information technology have a fundamental effect on construction labour productivity over recent years (Yi & Chan, 2014). Importance of innovation in material technology has experienced a greater long-term improvement in labour productivity (Naoum, 2015). The sophisticated equipment contributes in eliminating factors that have influenced negatively on productivity by effective using of them (Durdyev, S. & Ismail, S., 2016). This concept complies with (Dozzi and AbouRizk, 1993) who mentioned that equipment and material as inputs have fundamental impact to improve the building production.

#### 3.8.3.1 BIM (Building Information Model)

BIM contributes in promoting the productivity rate in each of construction method. In prefabrication reduces the material waste and facilitates into compression of the overall project schedule (Chelson, 2010). Technology innovation as ICT (Information Communication technology) as Building Information Modelling and photogrammetry can enhance productivity rate through an optimal managing of the material tracking and supply chain issues (Eastman et al., 2011; Huang et al., 2009; Teicholz, 2013; CII, 2008; Grau et al., 2009).

Since BIM is used to coordinate complex building components any conflicts in the project´s plan is encountered there would be a greater understanding of what is to be built. This coordination reduces number of the errors made prior to the actual construction operation starts. It also minimizes the time delay and rework that results in project cost overrun. The graph below shows that the BIM process forces more design decisions to occur earlier in the project when impacts on cost are lower. It explains how much ability the design changes have to impact the project cost between different project´s stages (Chelson, 2010)

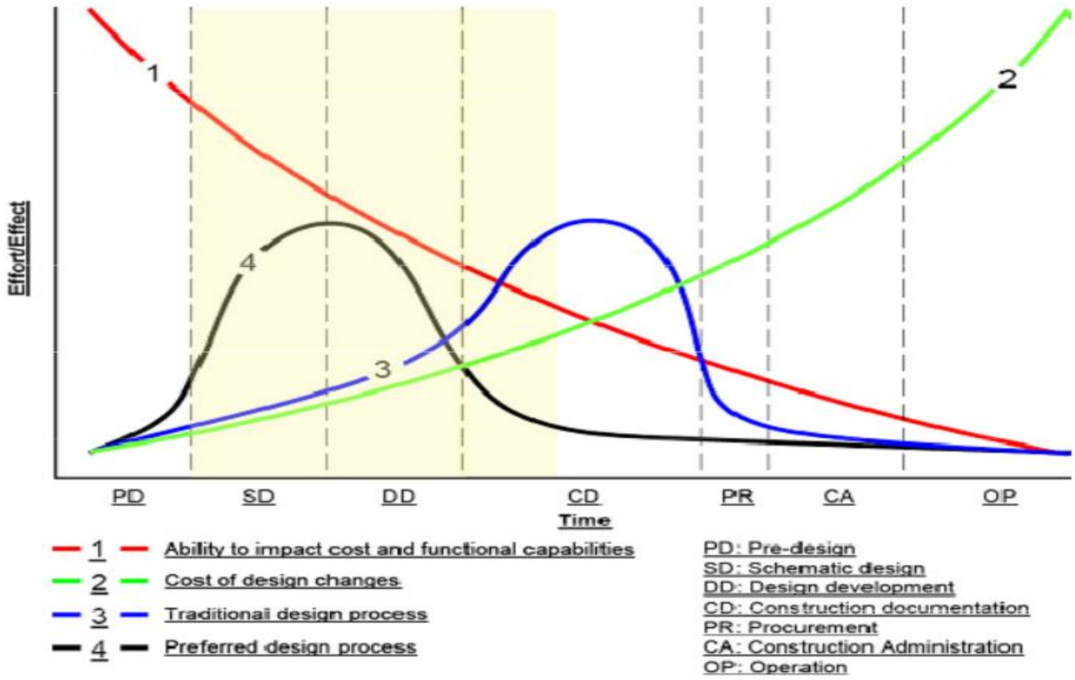


*Figure 3.8 utilization of BIM in all project phases, design change impact on costs Source: (Chelson, 2010) &(CURT WP 1202, August 2004).*

Using 3D technology with CAD computer aided design to Computer Aided Manufacturing (CAM). CAM approach such as BIM building information modelling could be used as a tool for transferring activities from the site to the supply chain the use of prefabrication construction (Ghosh, 2015).

Researchers have shown that resources spent on the models before the construction would decrease the amount of changes and delays. BIM usage drastically reduces requests for information (RFI) because the intent of the design is more clearly understood and building products will be closer to the objective of the design. Expending effort and money up front in the planning and design stages directly affects the productivity in the field. (Chelson, 2010). Some advantages of BIM using could be highlighted according to (Ghosh, 2015) as below diagram:

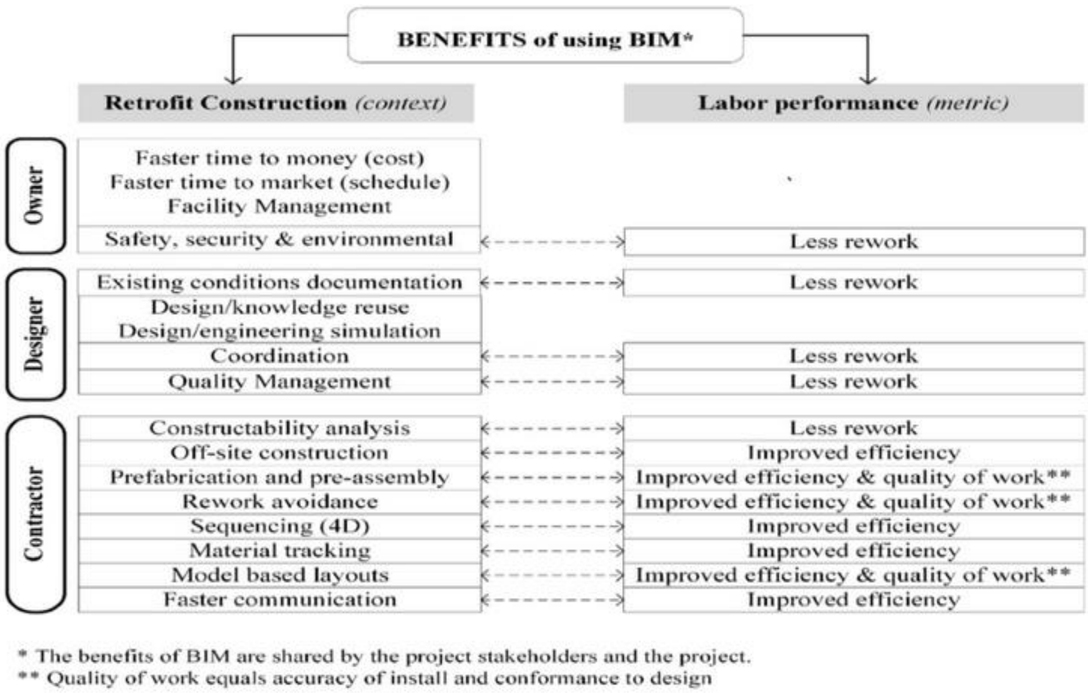


*Figure 3.9 Advantages of using BIM as a project planning software for all parties*
*Source: (Ghosh, 2015)*

#### 3.8.3.2 Using Wireless Communication & ICT for Material Management

Construction materials is accounted for 50-60% of the total project cost in the construction project. Materials management and tracking are vital functions for improving productivity. Therefore, poorly practicing this management affects the construction time due to applying the traditional method of paper-based techniques for tracking of materials. ICT in materials management has the potential impact to eliminate the work delay, idle of labour, and operational cost. In previous method of construction, ICT was only used for material management, cost estimation and scheduling as using Microsoft Power Project. However, there is not much use of modern ICT tools as e.g. wireless communications to easier managing and tracking for materials and tracing the process accurately (S. CHANDAR et al, 2016).

The main objective of this technology is to ensure that right information is available at the right time and in the right format to the right person to manage the right materials. It enables traceability of materials from the manufacturer towards the downstream (distribution) which increase the quality of supply chain operation. (S. CHANDAR et al, 2016).

### 3.8.4 Buildability

Adopting buildability principles in the design phase contributes in optimizing the integration of construction knowledge in the building process. It eliminates various project constraints which would result in poor labour productivity. They are 17 attributes according to (Mydin et al, 2012) as follows:

1. Design documents shall focus on innovative construction method by iterating design approaches.
2. Information on site conditions and terrain characteristics should be accurate.
3. Repetition of same sizes of components which reduces learning time.
4. Previous experience in design on works below ground level such as excavation works.
5. First time used material shall be tested whether the site layout is applicable or not
6. Universal components would save resources and increase flexibility.
7. The drawing should be simplified with sufficient clarity to ensure the minimum ambiguity.
8. Using of visualization Aids improve the application and compatibility of design drawings on the ground
9. labour and skills requirements must be taken into account by the design team.
10. Locally manufactured products the most dominated materials.
11. Having primary knowledge of the equipment and the plant by the design team would lead to more effective usage of the design documents.
12. The environment and layout around the site with restrictive characteristics of site condition
13. Using of similar materials which make laborers complete the whole work with minimum interruption.
14. The construction sequences
15. Considering weather impacts and possible timing to avoid carrying out structural work, external finishes,
16. Safely handing over the interchangeable tasks between the multi-disciplinary of high rise building should occur.
17. Large quantities of material waste became the largest consumers of natural resources (Mydin et al, 2011).

To summarize all the theories concerning labour productivity, many researchers have argued about benchmarking of productivity and every researcher has its own model in determining this benchmarking. As Per-Erik Josephson has argued that 17,5 % of the work time was only the direct work which has increased value on construction while 45,4 % was regarded as preparation and support work. He also mentioned that 33,4 % had neither added value on construction as rework and waiting for materials with interruption. So, these indications have focused on time usage percentage on the entire project level in terms of value adding perspective. While other researchers as Thomas and Zvarski have seen into productivity through benchmarking model of measuring projects attributes of the baseline productivity, waste and management indexes. Apart from all these theories other researchers argue about the impacting factors which have affected on variation in the workforce´s as technological, management and human factors.

Lack of buildability and design incompatibility to the site condition with procurement process have been argued as direct factors impact on reducing the labour during the pre-construction stage. While supply chain, site asset management and a weak site supervision have been referred to lower labouring rate during construction stage. Improvement strategies have been argued briefly as response to the significant variation in productivity due to some factors which have impacted negatively.

To validate and examine the reliability of theories stated by the researchers in this research an empirical study as a field engineering experiment has been conducted. This to verify the credibility of those statements as included in the result part of this study following:

# 4 Empirical Results

This empirical study is an experimental view on the topics discussed in the theoretical section in accordance to the interviews conducted with a site manager from a Swedish middle size construction company named Botrygg. The most significant benchmarking attribute of baseline productivity has been calculated for three project cases in order to assess their labour performance variations in a comparison process between projects respective attribute indexes. This empirical study comprises of a study which covers two main parts performed on the construction site. First part is a measuring process to estimate labour hours waste in construction, by applying Work Sampling Technique of collecting observation. The second part is to analyse the related activities proportion which caused waste in time to identify factors impacting labour productivity variations and establishing an improvement plan to the site manager.

## 4.1 Benchmarking of Baseline Productivity

Botrygg has adopted the Swedish Manual of New Construction List (Nybyggnads lista) for the newly built projects, to make sure that the construction operation corresponds to the project objective. It also ensures an effective usage of resources to produce the required building units. This list contains all required standards of material quantities and p-hours that were needed to construct each building component. It guided the site managers to identify what has been missed to be built in comparison with the initial planning schedule. Any clear differences which were found in the production level, remedial actions were taken to cover the missed elements that were unbuilt. But this process still lacked a methodology to pinpoint the impacting causes and measure those indexes which have resulted in the project´s lower productivity. Therefore, a more effective measurement model of productivity benchmarking is required to be implemented to compare the project´s productivity attributes with the same company´s previous or current project attributes.

To apply this methodology, the variations in projects productivity should be taken to account based on Thomas and Svarski model in the literature review part. Therefore, the most potential benchmarking attribute of baseline productivity should be measured and compared with same attributes from other projects. Two completed projects of Tyresö and Övre Vasastaden along with the ongoing project of Fallskärmen in Örebro have been studied to measure this baseline productivity.

The benchmarking of construction productivity measurement was done from the information that is provided by the contractor. The information and data which was taken covered the reinforcement task concerning areas produced during particular number of hours with a fixed number of (10) laborers. This data would be tallied in equations to find the average of labour productivity between three particular projects.

20% of the total reinforcement work task has been selected from the projects of Tyresö, Övre Vasastaden and Fallskarmen.the reinforcement task has been chosen based on it´s the most labour oriented work task. Although this task could be diversity in the number of laborers and, the company uses a constant number of 10 laborers for this task. Each project case has its own specific initial daily productivity index value which is the average ratio of the total working hours to produce the total quantity of reinforced square meters. Based on this context the primary labour daily productivity value is accounted for each slab and then the final average of the respective project slabs´ baseline productivity has been calculated using the below Eq. **No (1):**

$$\boldsymbol{Unite\ rate} = \frac{\textbf{Input}}{\boldsymbol{Output}} = \frac{\boldsymbol{WHs}}{\boldsymbol{Unit\ of\ work}} \qquad \boldsymbol{equation\ (1)}$$

Thus, the unit rate of direct work inputs divided by the output (WHs per Units of work) functions as the labours productivity baseline. As such to predict the productivity rate and all the efforts required to complete the reinforcement activity, the cumulative productivity of the total work hours for the total square meter reinforced areas has been measured for all the three projects of Tyresö, Övre vasastan and Fallskärmen for only the targeted slabs.

The performance ratio PR variation was found out between all the three project cases to know which one has experienced the best respective the poorest labour performance done. Also, their Projects´ Management Indexes are measured to determine poor material, equipment, information flows and improper planning that the respective task was exposed to. An analysis of all the cases was done in a comparison process between all those measured attributes to decide how this variation in labour productivity has proceeded gradually throughout the projects.

## Case study 1 Tyresö

The baseline productivity average is measured by considering an activity that covers 25-40% time of the entire project. 25 % of collected data for the reporting period out of 100 % of the total reinforcement tasks was covered. This project is at the final stage and nearly completed as detailed in the following table.

*Table 4.1 Baseline data collection for Tyresö reinforcement slabs*

| level no | Day no. | total quantity (m2) | Total work hours (hr) | Labour daily prod.(whr/m2) | Baseline daily |
|---|---|---|---|---|---|
| **1** | 9 | 850 | 719,3 | 0,84 | * |
| **2** | 5,5 | 695 | 416 | 0,6 | * |
| **3** | 3,5 | 457 | 274 | 0,6 | * |
| **4** | 3,5 | 448 | 275,9 | 0,62 | * |
| **Roof level** | 3,5 | 437 | 269,1 | 0,61 | * |

The sum of lowest indexes of labour daily productivity 0,84, 0,6, 0,6, 0,62, 0,61 divided by 5 scores (n) = **0,65 WH/m2** is the average of the best baseline productivity in all slab levels of reinforcement task in Tyresö project.  As it´s observed that there is a significant labour performance variation to deliver the required unit areas for each level which is shown in the following diagram.

The * symbol denotes the lowest value among the indexes of labour productivity.

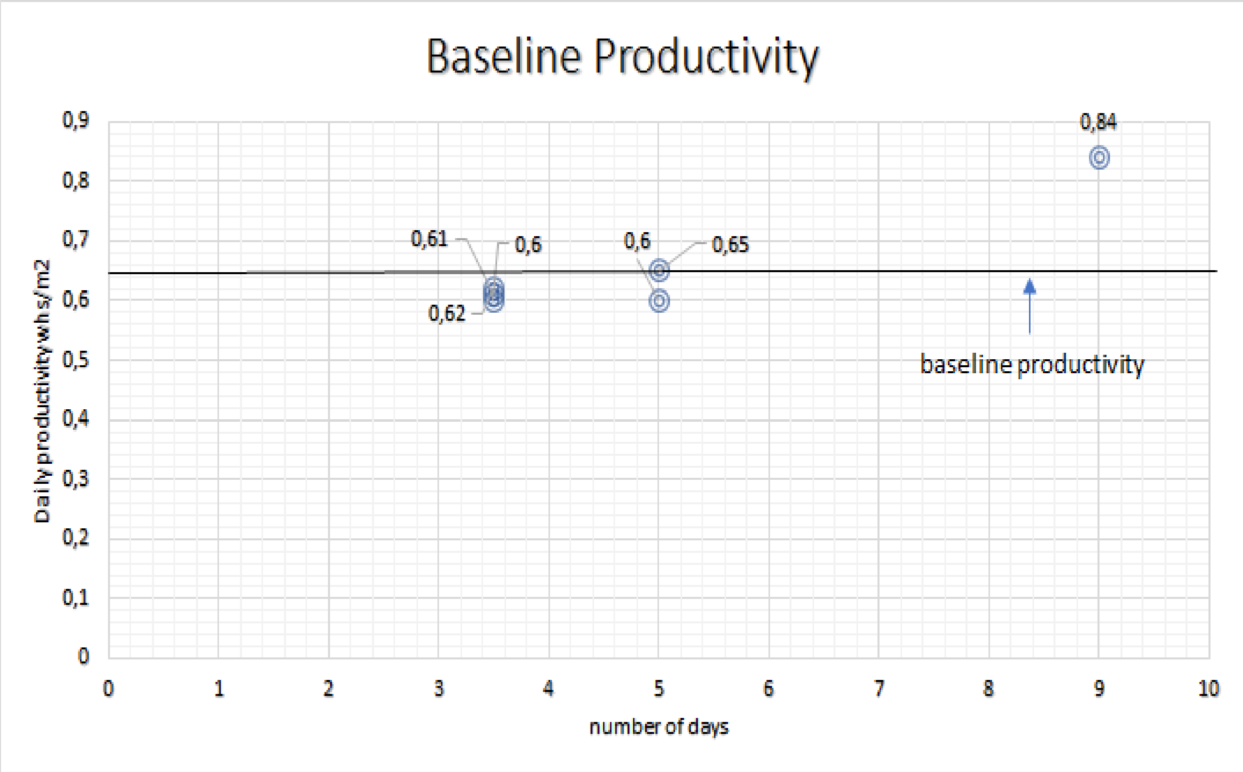


*Figure 4.1 Variation of indexes for Tyresö project baseline productivity slabs , average of baseline productivity for all slabs*

Each round dot in the diagram above represents an index of the daily labour productivity of total working hours spend on reinforced area of square meters produced for the respective slab. The line across the dot **0,65** in the graph shows average of the best baseline productivity measured for all the slabs covering 25 % of the entire slab reinforcement work.

Since determining of the waste index for each project should base on measuring other attribute as cumulative productivity(CP), therefore CP attribute should also be measured according to equation **no. (2)** as follows. It is the final work hours charged for total quantities done.

$$\textit{Cumulative Productivity} = \frac{\textit{Total work hours charged to a task}}{\textit{Total quantity installed}} \qquad \textit{equation}(2)$$

$$719{,}3 + 416 + 274 + 275{,}9 + 269{,}1 + 268 + 258 = 2481 \text{ WHrs total work hours}$$

$$850 + 695 + 475 + 448 + 437 + 457 + 457 = 3818\, m2\ total\ reinforcement$$

$$Cumulative\ Productivity = \frac{2481\ h}{3819\ m2} = 0,65\frac{Wh}{m2} \quad total\ quantity\ installed$$

Also, to identify the project´s activity performance, the performance ratio is measured as equation no. (3) which is a comparison against the best overall performance of the projects:

$$Performance\ Ratio = \frac{Cumulative\ Productivity}{average\ of\ baseline\ productivity} \qquad equation(3)$$

$$Performance\ Ratio = \frac{0,65}{0,65} = 1$$

The amount of labour waste in the project PMI waste index was measured as equation no. (4) below:

$$PMI = \frac{Cumulative\ productivity - baseline\ productivity}{baseline\ productivity} \qquad equation(4)$$

$$PMI = \frac{0,65 - 0,65}{0,65} = 0,0 \quad project\ waste\ index$$

The project has the lowest index which indicate the best management practice was experienced.

## Case study 2 Övre Vasastaden

The data collected of the reporting period is the same case as Tyresö project as it´s nearly completed by Botrygg. The measurement covers 25-40% time of the entire project. 25 % of collected data of the reporting period out of 100 % of the total reinforcement tasks was covered. According to the table below the baseline productivity is measured for this project.

*Table 4.2 Baseline data collection for Övre Vasastan project reinforcement slabs*

| level no | No. day | total quantity (m2 | Total work hours (hr) | Labour daily prod.(whr/m2) | Baseline daily |
|---|---|---|---|---|---|
| **plan 4** | 24,5 | 1775 | 1960,2 | 1,1 | |
| **plan 2** | 13 | 815 | 1024,1 | 1,256 | |
| **plan2(garden)** | 14,5 | 755 | 1157,3 | 1,53 | |
| **Over garage** | 11 | 850 | 853,9 | 1 | |
| **plan 3** | 9 | 740 | 707,9 | 0,956 | * |
| **plan 6** | 4,5 | 365 | 349,1 | 0,956 | * |
| **plan 6** | 6,5 | 380 | 523,1 | 1,37 | |
| **plan 5** | 9 | 745 | 712,6 | 0,956 | * |
| **plan 7** | 4,5 | 366 | 350 | 0,956 | * |
| **plan 7** | 5 | 280 | 385,4 | 1,376 | |
| **plan 8** | 6 | 503 | 481,1 | 0,956 | * |
| **plan 9** | 4,5 | 366 | 350,1 | 0,956 | |
| **ground plate** | 23 | 1667 | 1840,9 | 1,104 | |
| **plan 1** | 19 | 1054 | 1476,2 | 1,4 | |

The sum of lowest labour daily productivity indexes is taken as the best performance labourers had among all the slabs. It indicated that **0,95 WH/2m** is the baseline productivity for this project which is the average of all those five indexes of labour daily productivity in the targeted level slabs reinforcement. As it´s observed that there is a significant labour performance variation in the few slabs while in some others there is no variation. This average of 0,95 index varies compared to baselines from other projects while it did not vary within the same project. Since those five highlighted indexes are the same there is no need for any graph to show variation of each slab´s daily productivity.

Total work hours:
1960,2+1024,1+1157,3+853,9+523,1+385,4+350,1+503,8+1840,9+1476,2+
707,9+349,1+712,6+350+481,1= 12675,7 Whr

Total quantity area:
1054+1667+366+366+280+380+850+755+815+1775+740+365+745+366+503=
10427 area m2

$$\textit{Cumulative Productivity} = \frac{12675,7\ wh}{10427\quad 2m} = 1,22\ wh/2m$$

$$\textit{Performance Ratio} = \frac{1,22}{0,95} = 1,28$$

$$PMI = \frac{1,22 - 0,95}{0,95} = 0,28 \quad \textit{project waste index}$$

The lower index there is, the much better management practice would be experienced

## Case study 3 Fallskärmen

The project consists of multi-floor residential apartment building in Fallskärmen of Örebro city. The following table contains all the values concerning the total work hours, total square meter produced, the daily area and labour productivity indexes for Fallskärmen project. More than 20 % proportion of data reported was taken out of 50 % of the entire project work. As the reinforcement work was still ongoing and has reached on the fifth level which was half way through the project´s time span and completion date. The data was analysed according to the following table:

*Table 4.3 Data from the Fallskärmen project reinforcement task*

| | **no. days /person** | **Total quantity m2** | **Total hours WHs** | **daily productivity average WHs/m2** | **Baseline daily** |
|---|---|---|---|---|---|
| **foundation** | 3129,6/80 h = 39 days | 2281 | 3129,6 | 1,37 | * |
| **plan 1** | | 1130 | 1170,1 | 1,03 | * |
| **plan 2** | | 1111 | 1086,3 | 0,98 | * |
| **plan 3** | | 1109 | 1064,8 | 0,96 | * |
| **plan 4** | | 1122 | 1072,2 | 0,95 | * |

The baseline productivity per slab reinforcement task is the average of the five lowest calculated values of daily productivity in whr/m2.This means that the sum of the lowest index of labour daily productivity 1,37, 1,03, 0,98, 0,96, 0,95 divided by 5 cores (n) = **1,06 WH/2m**. This index was regarded as the average for all slabs daily productivity in terms of working hours per square meter which covers 25% of slabs reinforcement work. The variation and average of this baseline is shown in the following graph:

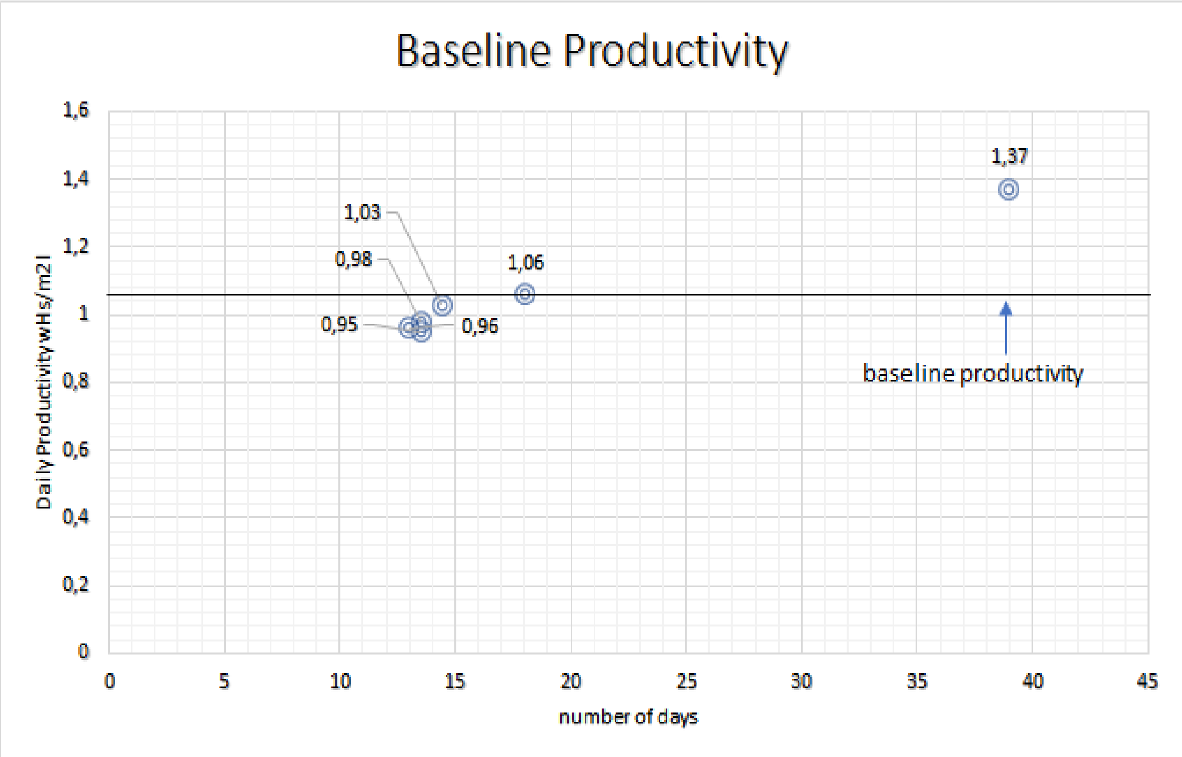


*Figure 4.2 Variation of indexes for Fallskärmen project baseline productivity slabs, average of baseline productivity for all slabs*

The dots represent different indexes of daily labour productivity of total working hours per reinforced square meters for each respective slab and the line across 1,06 in the graph is average of the best baseline productivity for all the slabs covering 25 % of slab reinforcement work of the respective project.

Performance ratio and PMI attributes of Fallskärmen were measured based on the previous calculations as follows:

Performance ratio (PR) = 1,4

Project management index (PMI)= 0,4

.

To assess this baseline of labour performance, there is a need to conduct a comparison between all obtained values from these cases. This process determines which project case has the best labour efficiency in terms of the highest daily labour productivity, and how this baseline variation has proceeded forward.

## Best Baseline Productivity Comparison in All Three Cases

The Difference in baseline productivity values of WH/m2 among all the three projects, was a clear indication of gradual variation and significant reduction in labour productivity from a higher unit rate to a lower rate. The highest value of baseline productivity index would reflect and indicate the lowest labour productivity that the project has experienced.

Data of the baseline productivity from all three projects were compared and it was found there was significant decline in labour productivity between the projects. The 1st case study has the highest labour productivity then gradually it went down in the 2nd case and even more downward in the 3rd case study

Tyrsö project baseline index was 0,65 which is the best rate of labour performance in comparison with both Övre Vasastaden which had 0,95 indices and Fallskärmen which had 1,06 indices. So, the baseline productivity value is gradually descending from the first case study to the third one. It was found that Fallskärmen as a case (3) had a highest baseline productivity value which indicates the worst performance which is regarded to be a serious decrease in labour productivity. Case study (1) of Tyresö had the lowest baseline value which is considered as the project has experienced the best labour performance among all cases. While case (2) value is located in between. This result shows a significant labour work variation between all the targeted projects. Implying this labour performance assessment resulted into a gradual decrease in labour productivity by starting from the highest performance as case one and ending with the case three that had experienced the lowest labour performance.

The PR performance ratio and the PMI project management indexes are quite clear indicators to show how this decline has functioned and effected on the productivity. When the PR index of Tyresö project which had index 1 compared to Övre Vasastan project which had (1,28) it was found that Tyresö has experienced a higher productivity level and has been more productive based on the lower the PR is the better the project performance would be. The same phenomena involve other attribute indicator as PMI that case of Tyresö had 0 index while Övre Vasastaden had 0,28 as the lower PMI index has experienced the better management role in the project. The data indexes shown in the following table:

*Table 4.4 Collection of data indexes for all project attributes*

| Project no | Baseline productivity | Performance Ratio | Cumulative productivity | PMI project management index |
|---|---|---|---|---|
| **1 Tyresö** | 0,65 | 1 | 0,65 | 0.0 |
| **2 Ovre Vasastaden** | 0,95 | 1,28 | 1,2 | 0,28 |
| **3 Fallskärmen** | 1,06 | 1,4 | 1,5 | 0,4 |

It was noted that there was a gradual decline in labour productivity from case 1 to case 2 and so on to case 3.

As the result from applying the benchmarking of all the three projects labour productivity has proved a serious decline outcome. This result for all three projects were based on the total and cumulative number of labour hours spent on 25 % of reinforcement areas involved for the entire projects. Implying the benchmarking is a metric system of the projects performance rate which measures the final productivity index for a specific task which involved in the entire project. This method measures only the indexes of the project attribute. It cannot illuminate the responsible impacting factors influencing this decline. It`s not a proper tool to rely on in pinpointing the type of gaps in activity elements which impeding the workforce to increase the value adding works on construction.

Therefore, there is a need to identify the management gaps which have caused this labour decline in projects productivity. There is a need to apply a practical mechanism and a functional analysis to measure the current state of practices implementation within a company. There is a need to determine what steps need to be taken to improve their practices from its current state according to (Haas ,2017). This tool measures the wasting of labour hours with respect to the total day hours. This tool called "activity analysis "which helps to find out all non-added value activities in the project. This activity analysis determines correlation between both the productivity and direct work rate. These tools classify the task into synthetic elements to analyse the defects in the management practice. In additional of that this technique helps to make an improvement strategy plan to mitigate those obstacles and the decline impacting factors to boost labour productivity as described later on.

The activity analysis of Work Sampling method has been adopted on Fallskärmen residential project based on (Haas ,2017and Gouett ,2011) benchmarking performance metric system of the direct work rate. It efficiently measures the time expenditure of workers on-site. The aim of this analysis was to identify productivity inhibitors which should be eliminated by the management. Also, to provide workers more time for direct-work activities and identify the practice elements which need improvements. The assessment of direct work rate has been conducted to find the proportion of time that workers can dedicate to specific activities and define the practice elements which need improvements

## 4.2 Work Sampling Method Technique

Work Sampling technique is applied in the project of residential building of Fallskärmen to analyse the laborers performance rate. To identify those reasons that were responsible for the decline, the Work Sampling methodology was adopted in the third case study of Fallskärmen together with site manager´s interview sessions. The data helped to find the ratio percentage of both productive work and unproductive activities performed in the construction sites. Many managerial reasons of rework, wasting in construction time and work interruption were directly linked to the decline in labour productivity during two stages of pre-construction and construction.

This method can function as a detecting approach to find out the failure in pursuing the required level of work and diagnose the major factors resulting in poor labour performance. The analysis outcome of this method determines how much labouring time spent is being non-productive in relation to the total time the person is involved in the operation. It establishes the foundation for an improvement plan for managing those shortcomings. Applying this technique in taking observation data was conducted on slab reinforcement task through classifying this task into three main parameters as direct, support(indirect) and no-working as described details in the following sub-section table:

*Table 4.5 Activity task classification modes in reinforcement*
*Source: (Carl Haas, Waterloo University ,2016) (CII,2017).*

| **Classification** | **Productive** | **Semi-productive** | **Non-productive**<br><br>**(No-working)** |
|---|---|---|---|
| Description | Fully productive &direct work | Semi-productive as indirect work | Non-contributing to any activity |
| reinforcement activity | *Exerting physical efforts directed towards the activity.<br><br>*laying reinforcement bars& fixation<br><br>*Fixing the balcony slab<br><br>*reinforcement bars bending work | *Preparation work to assignment and determine requirement<br><br>*Material movement.<br><br>*Scaffolding as preparation for slab fixing.<br><br>*Taking instructions.<br><br>*Equipment & tool movement.<br><br>*Equipment adjustment & (set up) | *Waiting period of idleness (personal break).<br><br>*Hanging about empty handed.<br><br>*waiting for more instructions.<br><br>*waiting for equipment to be fixed.<br><br>*waiting for materials<br><br>*equipment movement.<br><br>*Personal breaks |

Each of the above site observations has been taken and measured on the bases of time expenditure. How much time lasted for each activity has taken was measured together with how much wasted time each activity involved in compared to the total time of p-hours spent on site. The above parameters of non-productive work as non-value added and fully productive as value added were criteria´s to estimate the percentage rate of utilized and unutilized time. The indexes below were the final result after conducting a field study of data collection through site observation. The following graphical chart depicts labourer's performance proportion for all the labour-hours which were utilized and not utilized according to the descriptions classified in allocation percentage table no (4.6) included following:

*Table 4.6 Percentage allocation for Fallskärmen reinforcement task*

| Work utilization | site labourer performance |
|---|---|
| non-productive | 0,62 |
| semi-productive | ,0,13 |
| fully productive | 0,25 |

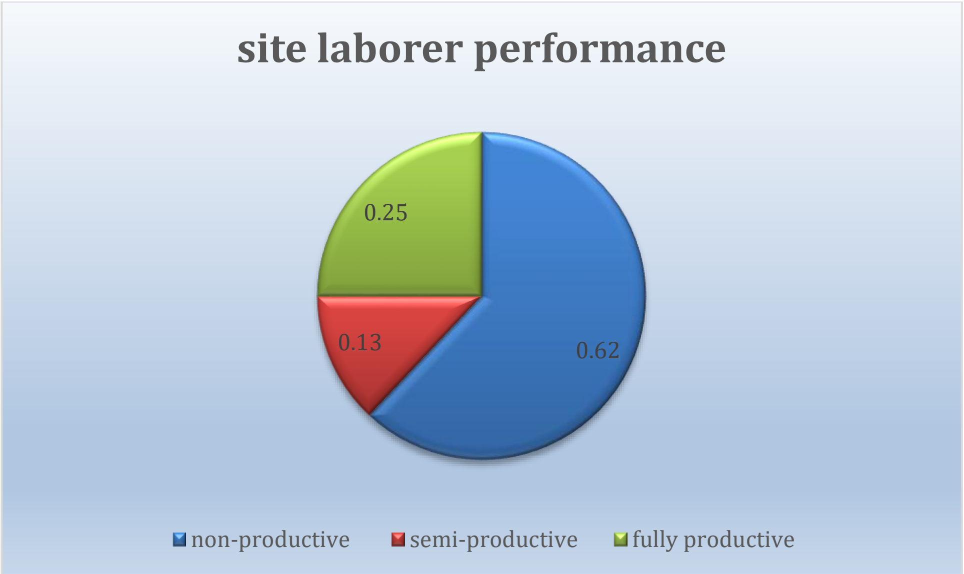


*Figure 4.3 Proportions of Fallskärmen reinforcement productivity for both non-value and valued activities indexes*

This following graphical chart represents the percentage of man hours effectively utilized as value added work and ineffectively utilized as non-value-added work out of the total working hours. Each activity has been allocated its own specific percentage shares. 75 % of the total reinforcement working hours was estimated as non-productive and 25 % as a productive and a direct work hour during the whole days of observation taking. The allocation sharing relied on the data contains in the table no 4.7 below which is graphically showed in figure no 4.4. The figure shows a distribution shares between all the value-added and non-value-added activities for Fallskärmen project during conducting the Work Sampling Method.

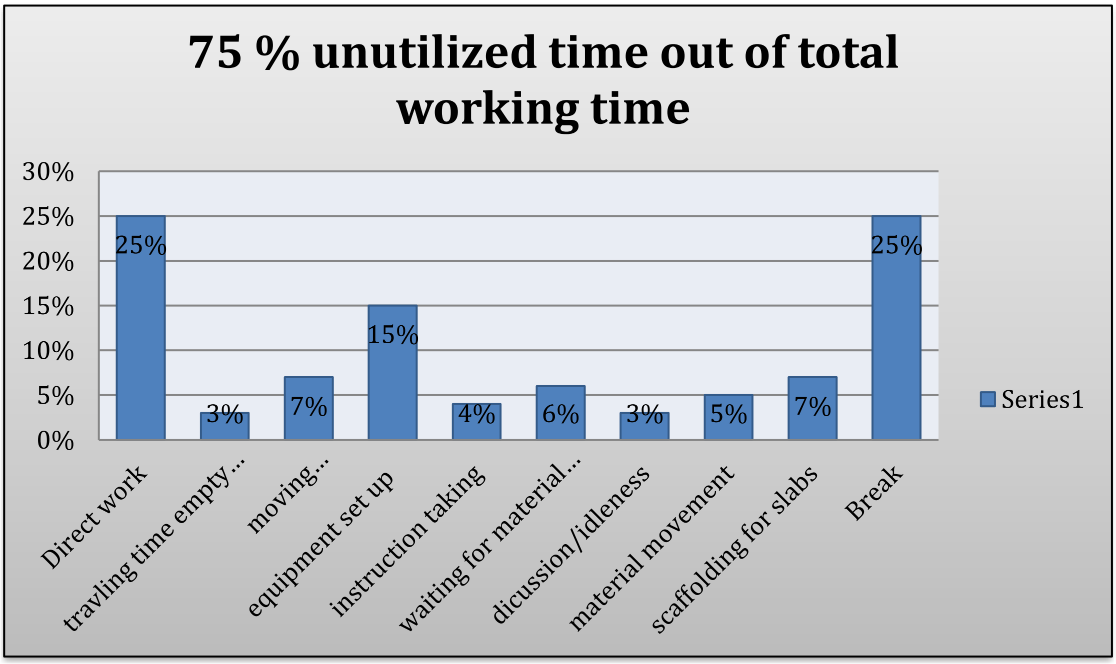


*Figure 4.4 Allocation of percentage shares for each activity involved in reinforcement*

*Table 4.7 Ppercentage shares of non-value activities impacting the workforce decline out of 100 % of working hours.*

| | | |
|---|---|---|
| traveling time empty handed | 03 % | 139 min |
| Direct work | 25 % | 1188 min |
| equipment /storage area movement | 07% | 354 min |
| equipment set up | 15% | 720 min |
| instruction taking | 04% | 173 min |
| waiting for material arrival | 06% | 308 min |
| discussion/idleness | 03% | 148 min |
| material movement | 05% | 220 min |
| preparation work for slab/scaffolding | 07% | 350 min |
| Break | 25% | 1200 min |

The table no 4.8 contains percentage shares for all activities with respect to their ranks of relative importance index which have impacted on 75 % wasting time. It shows which activity had the highest influence on the workforce´s productivity decline in the task. The most effective activity has impacted was graded with a highest relative importance index and the lowest rate had the minimum impact on productivity decline.

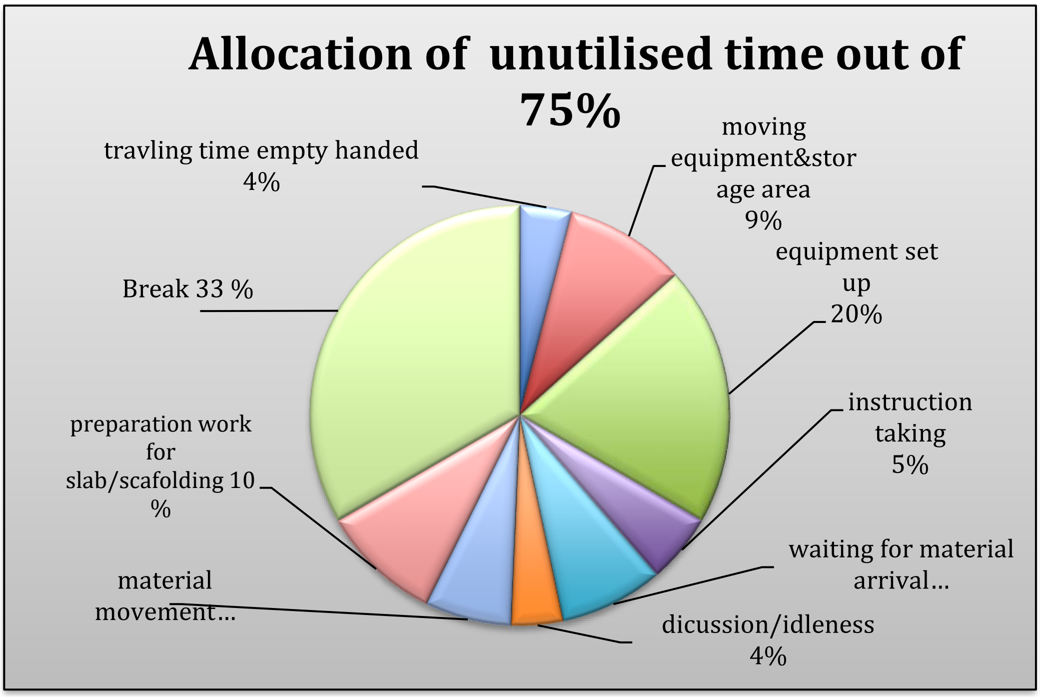


*Figure 4.5 distribution of percentage shares to productive & non-productive activities*

*Table 4.8 Relative importance percentage shares distribution of non-value adding activities &wasting time*

| Activities of non-productive and support work | Relative importance index | Rank |
|---|---|---|
| Break | 33 % | 1 |
| Equipment set up | 20 % | 2 |
| Preparation work for slab/scaffolding | 10 % | 3 |
| Moving equipment storage area | 09 % | 4 |
| Waiting for material | 08 % | 5 |
| Material movement | 07 % | 5 |
| Instruction taking | 05 % | 5 |
| Traveling time empty handed | 04 % | 6 |
| Discussion & idleness | 04 % | 7 |

As a result of applying WSMT method many causes for decline in labour productivity and time delay has shown up together with pinpointing those reinforcement elements which need improvements. Adopting this method of activity analysis helped to find the responsible factors for productivity decline and reduction in their value-added activities. The following factors became as foundation stones for making an improvement plan to mitigate the managements and technological risks as were studied in below section:

## 4.3 Impacting Factors on Reinforcement Productivity

Both pre-construction and on-site construction factors became highlighted in Fallskärmen residential building site which resulted from activity analysis as below:

### 4.3.1 Impacting Factors in Preconstruction Stage

The preconstruction stage is an integral stage in deciding how a project will turn out to be. The most prominent part is that this stage will decide on what option a contractor can have at his disposal to manage productivity. This is a key stage which can make the factors which were discussed in the earlier sections relevant to the project. A few of the risks which are important according to the site manager have been shortlisted below:

#### 4.3.1.1 Design Incompatibility with the site Condition

It´s a significant challenge to make the design specification compatible to the site conditions, which can be the potential issue to reduce the labour performance. As Botrygg is not directly engaged in producing any design documents, it was noticed that there is a great need for the site manager to coordinate with the design team to obtain a clear vision of the design specification and make it compatible to the site layout. It implies that the design complexity and uncertainties is regarded to be the main source to request for more detailed technical information. This led to loss of a huge amount of work time and ceased the construction operation often. WSM analysis result has contributed to 08 % of time is being wasted to request for information in the reinforcement task.

Another prominent issue is the mismatching of the precast element design to the cast-on-site structural elements. For example, adjusting and fixing work of a ventilation component was needed when the opening was designed on the wrong side of the wall element. The ventilation opening did not correspond with the existing design structure of the slab built through cast-on-site. In this case, precast elements were returned to the manufacturer who was responsible for the repair works and amendments. This was a time-consuming process which left some gaps in the slabs to be reinforced afterward and delays the reinforcement work in waiting for the remaining elements to come back and be installed in place. These cases often faced Botrygg because the precast wall elements were outsourced to a manufacturer who has its own separate designer, while the building´s structural design was outsourced to another designer as Ramböll. Also, sometimes the pre-fabricated elements might have to be fixed by the contractor through refilling gaps in order to compact and adjust them to the cast-on-site elements in a rework process. So, this issue had to be handled manually for correction that contributed into too much rework by laborers. All these cases have turned up unexpectedly when the things are installed wrongly as a negative outcome due to improper design procurement and mismatching issue as shown in this picture:

*Figure 4.6 unconformity of stairs design to the structural design framework*
*Source: Botrygg, Örebro, Fallskärmen residential project*

Incompatibility of the stairs design with the structural framework design was one of the major issues encountered the construction work. The prefab stairs were provided by a certain supplier which had its own designer who had no any vision of the framework´s design attributes. The building´s structural design detail drawings had not been accounted for to match the stairs design. The stairs required more spaces to be installed in place correctly than the space which the framework had. The stairs design had a bigger inclination angle than they were supposed to have with respect to the accommodation. This caused work interruption and spending time back and forth with the supplier to resolve the issue. Consequently, to put stairs in place some adjustment works had to be done with inner side of the framework as too much rework which have affected negatively for being behind the schedule.

#### 4.3.1.2 **Improper Planning software tool**

MS power project is a form of traditional ICT (Information and Communication Technology) which is used by the company for planning and estimating the project´s budget, quantitative data and the time schedules. This tool cannot determine how many products can be finished and produced with a certain amount of raw materials, which makes it unsuitable for solving problems of shortage for materials. This software does not bring and involve all the project actors in practicing their management roles to adhere with the schedule. In additional of that this software lacks the ability to track the materials due to the lack of communication with the material suppliers which is one of the contemporaneous issue related with delivering materials on time. However, it is a good tool to make the quantity take-Off and calculate the cost estimation.

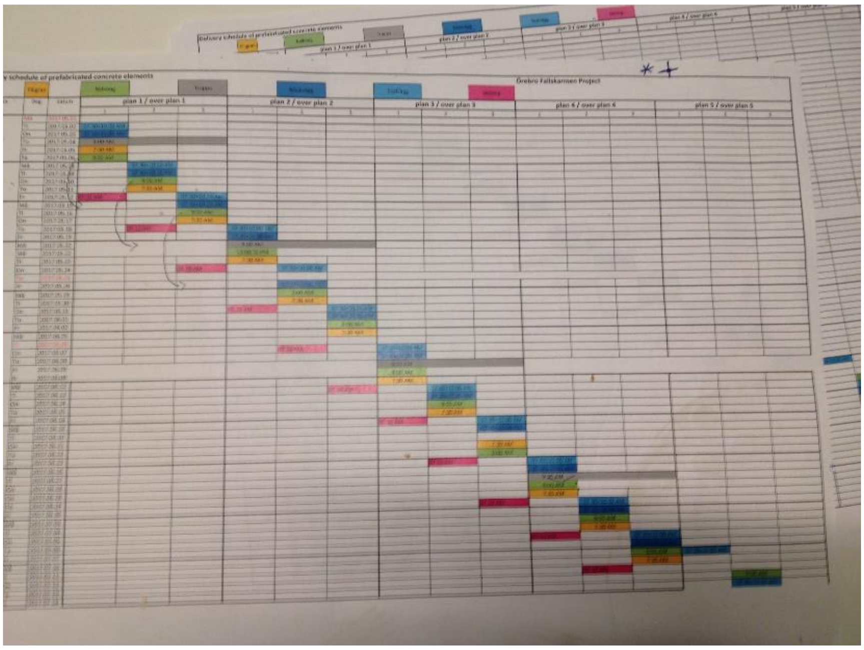

*Figure 4.7 MS power project planning software being utilized for project planning*
*Source: Botrygg, Örebro, Fallskärmen residential project*

#### 4.3.1.3 BIM

Botrygg does not use BIM or any of it tools for planning which is a big disadvantage here when BIM is not fully brought into the construction fold. As it integrates all the project phases from the feasibility studies through the planning phase ending with the construction stage. However, the company uses AutoCAD which was 2D drawing software and had not enough detailed information for the construction elements. CAD does not fully provide the complete design description for the building materials components and how they look like in reality. Therefore, the designer´s specifications would not be fully understandable by the contractor as needed in order to adapt the drawings with the site conditions. AutoCAD has its own limits to what extent it can benefit at the preconstruction stage. The aim of the preconstruction stager to visualize all the possible solutions and risks that can be encountered. The design work which was done to Botrygg was in a simple 2-dimensional which was procured to a special consult. The contractor was forced to contact the designer for meeting in case of require to clarification. If the company had used BIM it would have resolved incompatibility issue easily with this 3D model which can help in clearing all the minor issues.

#### 4.3.1.4 Ground data and research

The case study at Fallskärmen has a complication in the ground. The foundation was supposed to be designed stronger than a normal building due to the upward water pressure from the ground. The stronger foundation required more labour hours with more risks of rework as non-value-added moments. This issue has caused to waste larger human resource to build a heavier foundation. If Botrygg had done its research before the plan of construction on the ground conditions, it could have chosen a better alternative to the current project as predicting of spending more resources both in human efforts of labour hours and building materials in the preplanning phase. Another alternative which could have been an optimum solution was to choose a better location to carry out this project on to overcome the risk of the geological ground erosion for the foundation.  According to the site manager," the *water was being constantly pumped out and the foundation has been made heavier and deeper so that the building can handle the upward thrust''*[1].

*Figure 4.8 Geological condition of the foundation water wasted larger human resources Source: Botrygg Fallskärmen residential project in Örebro.*

## 4.4 Factors During Construction Stage

These are the factors that are in the boundaries of the contractor's responsibility, which involve the project´s activities on site. They not only cover the reinforcement task, but they concern every single task confined to the scope of the project, which are mentioned below:

### 4.4.1 Planning & Management

The site supervision which required for cast-on-site construction should be more intensive due to including of multiple tasks as reinforcement, framework and concrete casting. Every task has its own professional labour, like the formwork needs a qualified carpenter and the reinforcement task needs skilled steel labour. Therefore, for the efficient execution of these tasks, an intensive supervision required to pursue that the proper work is done permanently. Any disruption or change that occurs in the critical path by postponing or forwarding any specific task due to material delay, would interrupt the entire crew work and minimizes an efficient labour performance. As it was

[1] Fallskärmen Project site manager Hogar Lak, 2017

found that the late delivery of precast wall elements has delayed the task of installing flat concrete slab floors by 06 % of the entire work time and ceased ventilation pipe-works in some part of the slab. This delay resulted into employing extra laborers to restore materials which were prepared for the ventilation task and wasted working hours unnecessarily. This occurred because of non-tracking of materials that are dispatched. Thus, the planning would be changed to execute unscheduled tasks instead of the targeted ones which have been planned for. *"Implying all construction methods need timely planning according to the respective site managers "*[2].

### 4.4.2 Request for Information (RFI)

The design was hard to be decoded and built, some parts were incompatible due to the site conditions which demands the request for the detail information. According to site manager since designers have not been on the construction site. They do not know how to build on the ground and do not understand the intensity of the design´s negative implications on site work when the drawings are incompatible and not done correctly. Based on this principle the request for information to search for the right and correct design intent would always be a current issue in pending for instruction. As such RFI has resulted into 08 %-time spending in seeking design instructions in the reinforcement task.

### 4.4.3 Construction Method

The type of construction method has a direct impact on the workforce performance. For example, in cast-on-site method any plumbing installation errors occur due to mistakes during casting of slabs, this has been dealt with and resolved through concrete breaking. This process caused waste in working hours to break concrete and put the relevant component in the right place. This aspect to crash the concrete has a hand arm vibration-syndrome on the laborers which has negative implications to decrease the rate of their productivity. *"According to the regulations, laborers can work on concrete crashing more than 15 minutes"*[3].

As reinforcement task is an essential task of cast-on-site, it´s materials are characterized by diversity in their forms and sizes therefore it was exposed to inappropriate installation occasionally. In additional of that because of this task was highly combined with plumbing and ventilation pipes it required an extra precision to install right components in right place. As such the construction work proceeding was slowly ongoing in this task even though the site condition was perfectly set up. According to the site manager *"projects with pure cast-on-site construction method should be extended about 6 months moreover its initial time schedule. While the same project size lasts for only 6 months in precast method"*[4].

Site manager´s example, "*three floors take six months to build up only the building structure in cast on site and the finishing work also takes six months including all disciplinaries for fifty apartments. The garage or parking only takes 110 days alone as a double time span than others due to detailed related works for reinforcing and casting the outer walls. Plumbing works in each slab level last for 10 days which means 30*

[2] Hogar Lak Fallskärmen site manager ,2017
[3] Fallskärmen site manager Hogar Lak ,2017
[4] Hogar Lak Fallskärmen site manager interveiwed 2017

*days. While casting-on-site for the garage outer walls need 17 laborers as a basic estimation but if the method had been a precast there would be a need only for 11 laborers for mounting the outside walls at all three levels"*[5] Implying casting-on-site is more time-consuming construction and more exposed for waste in labour productivity based on complexity in reinforcement task.

### 4.4.4 **Equipment & Material Quality**

Using of more advanced technology could have speed up production of more unit of square meter area. Using of sophisticated equipment was an extra cost burden on the contractor as lack of having a larger crane to move both material and equipment was the main factor to loss 09% work hours. Using of a quick scaffolding technology could have saved 07 % of waste in working time for preparation work in slabs as observed during the sampling data collection. Therefore using a larger crane could save about 10 % of the total days' time and p-hours spent on moving the storage area who the site manager was agreed about. So apparently lack of sophisticated equipment was a direct factor to loss 15 % of the day time in equipment set up and spend time for warming up at the start of working day during the WSM of activity analysis.
Material types and quality have a great impact on productivity level through material handling and processing perspective. The self-compacting concrete was a better-quality example of concrete which was used in casting on site. The much easier usability and workability with materials there is, the more faster construction work would be easy going to produce a larger amount of area. For example, *"using an electrical screwdriver instead of the traditional one produces more work and accelerates 10 % of the time spent to execute any task"*[6].

### 4.4.5 **Work Overload (Overtime)**

Extra work exertion on the laborers would have negative effects on their physical condition and their work performance. It was found during Work Sampling method observation that the crew size´s work performance has much reduced with 04 % of idleness and discussion. Also, some spent 03 % of work time in walking on the slab empty handed just one hour prior the lunch time to get a short pause. This was an outcome of physical overload and bulk of reinforcement work. According to the site manager *" people are not machines"*[7] therefore overtime work is not efficient and delivers a lower work productivity which can result into reworks.

### 4.4.6 **Supply Chain Logistic**

Adopting of just-in-time construction production method was applied in the project to avoid relocating back and forth of materials storage unnecessarily. Due to the fact that this method entirely depends on an accurate material delivery, accordingly the work was greatly exposed to disruption in order. Since site managers are frequently subjected to this logistical issue therefore, employing a part of laborers on another task was a real factor to loss the labour efforts. For example, the assembly of prefabricated slab floors

[5] Fallskärmen site manager Hogar Lak ,2017
[6] Hogar Lak ,2017
[7] Site manager Hogar Lak,2017

would not be commenced and placed if the required number of precast inner wall elements have not been already delivered. This is for the obvious reason that prefabricated slab floors are installed above the precast inner wall elements. . So eventually there would not be any scaffolding task ongoing because there were not any slab floors installed. The same case concerns casting work of the main concrete slab which would not be started unless the slab floor elements are installed. These cases happened occasionally on this site which led into work interruption. Thus, the intended reinforcement work area would be narrowed down merely on the completed ones until the supplementary elements would be installed. This issue resulted in more messy and site congestion as shown in the following picture:

*Figure 4.9 Gaps in the slab which became reinforced at a later stage in a rework. Source: Botrygg Fallskärmen residential project in Örebro.*

This aspect of tasks´ interdependency has led to restore and prepare the main slab´s complementary reinforcement rebars adjacent to the space where it was left for the delayed inner wall elements to be put in place. This was one of those cases that Fallskärmen project has suffered from regarding back and forth of materials moving which located close to the reinforcement point. Therefore 04% of work time has been wasted due to the issue of material management as shown in the following picture:

*Figure 4.10 removing and relocating reinforcement during material delays delivery*
*Source: Botrygg, Örebro ,Fallskärmen residential project*

So, inappropriate storing of materials on the building´s structure outside of the initial storage area would consequently results into unnecessary material movements afterward during a later stage of the project when the main slab concrete casting will be a current activity.

### 4.4.7 **Language Communication barrier**

Language issue regarded to be a minor problem which was impacting on the labour performance due to having a new strategy of employing foreigner laborers which can be supervised by homeland`s foreman. The project has employed Romanian laborers who were supervised also by Romanian supervisor. The aim of this monopoly was easier flow of instruction and information transfer between the same country´s laborers. As majority of Romanian supervisors are English speakers it simplifies passing of the project manager´s instruction through correctly. The supervisor´s role played an important role to keep the laborers updated and eliminate any sorts of misunderstanding which can lead to execute a wrong work. However, such employment can lead to additional expenditure on the site, but it can promote elimination of language barrier as major concern for dip in labour productivity.

### 4.4.8 **Weather Issues**

Heavy weather condition was a critical factor on site which influenced the laborers working performance. This factor affected the equipment and materials functionality in spending more time for warming up and set up. According to the site manager the employees were prepared to work up to –15 C temperature but they are also human beings who need care taking. As the weather condition was somehow hard to predict 100% as rain and storm the site manager was optimistic if one week ahead ascertain weather forecasting it could have ordinary performance for his labourers. During rain and storm there was no option to have rather than interrupting the entire work by halve of the crew and take turn with the other halve crew in having a short pause. As it was noticed certain laborers took frequent breaks due to bad weather condition which reduced the reinforcement effectivity. It was noticed that weather played an integral role in keeping a smooth flow construction productivity. As the site manager emphasized how planning ahead as predicting the weather a week ahead and keeping simultaneous activities, which were not dependent on weather was a very efficient solution to overcome such issues. However, it was noticed this was a big issue during constructing the building´s foundation and garage when there were not many simultaneous activates to do.

### 4.4.9 Human factors

With observations on the site it was evident that a large amount of time on site was spent on discussions without productive work during hours near to lunch and time before the site was supposed to close. It was observed that a certain dip in productivity approximately 8% of work time can be attributed to the sloppy and easy-going nature of the employees. Although this factor has no solution as such it can be reduced to an extent by taking measure to give a sense of commitment to employees by providing them with incentives to boost their morale.

### 4.4.10 Labour Skills Restriction

Restricting of labour skills sharing would complicate. Employing skilled labours on a specific activity which corresponds with their field of proficiency was regarded to be a success factor to increase productivity. This labour employment strategy of interacting the skilled one with the new upcoming laborers was not included earlier in Botyggs procurement policy. Botrygg employed new labours once a new project starts for construction. This contracting strategy had minimized the learning practice and knowledge transfer of experience sharing from the skilled ones to the unskilled laborers. Mixing of both could be a future demand to have new experienced laborers when there would be too much professional work needs skills to be covered up to keep the expected productivity rate.

# 5 Discussion

Since the whole construction relies on the demand for knowledge and need for instruction, employing of skilled reinforcement laborers could be a great impulse upon others to produce more work. This outcome could be obtained through sharing information more effectively. This result was noticed during the reinforcement task when the supervisor was not available on site, the access for information became limited and the work on site came to a halt. This brings forward the importance of having skilled reinforcement labourers, who can be a source of knowledge and replaces the supervisor´s role to a certain extend by informing the co-workers how to do the right task in the right place.

Optimizing labour productivity has a lot to do with the total area of the Project. The wider the area the project has, the more the possibility for introducing new technology. Such as, using multiple crane which speeds up the precast construction work. Tyresö, was the biggest project among the three. It had a wider area around to put more resources and equipment. Therefore, it has achieved the highest labour performance. The higher investment the project has the more innovative ideas can be tried out. Also, simultaneous activity to employ the idle laborers on other activities during the logistical and bad weather issues might have worked here to increase productivity. While this plan might not work for smaller size of projects as this small size residential project of Fallskärmen due to limited number of tasks.

Sophisticated equipment has a great impact on the labour productivity. It can produce more unit of areas, in accordance with the site manager. Since in this particular case study the investment was limited to the traditional machines, the site manager had substituted the machine power with human efforts. This was managed through increasing the number of laborers which reduced the productivity rate and the laborers performance level.

The speed of execution of a construction task can be determined by the composition of the current task which is executed. For example, the reinforcement task consistence includes too much repetitive technical details in structural K-drawings which needs higher accuracy and care to put things in the right place. Therefore, it could be one of the slowest tasks and less productive in comparison with concrete casting. The reinforcement task has hard-physical working condition, which requires work interruption and frequent rest especially during the bad weather circumstances. Thus, the crew performance might not be productive even if the laborers are hard workers.

Botrygg´s projects are somehow similar because of the similar design and same labourers used in most of their projects, these labourers keep repeating the same process in every project. Although learning through practice by repeating the same process many times enhances the labours efficiency, it had a certain disadvantage as well. The disadvantage was that the workers could get over confident in performing their tasks and which would lead to commit mistakes that can slow down the progress of work. This implied that it was essential to have a good knowledge management system to record the mistakes which were committed on site. Apart from the human errors these mistakes could have been specification details of materials and equipment used for that project. This registry system can help the contractor to make optimum decisions while selecting materials and equipment required for their projects which may eliminate majority of the rework.

Buildability is considered as an important factor here. The simpler the structural framework of a building is, the lesser the time is wasted of gathering information and it would yield lower construction costs. As buildability and constructability reflect the quality of the design; so, if design documents are difficult to understand, the project will be difficult to be built. Site managers reflection and engagement in meetings with the designer can ease the design to a buildable model, which can minimize the construction time and request for detail information. The design incompatibility implications which were encountered during construction phase requires a great challenge to find a proper solution in making the design work. Thus contractor´s engagement by attending meetings is one way of avoiding too much reworks by creating a transparent design in advance.

Adopting the precast construction method results in producing more square meters per hours of prefab walls and stairs due to less need for human efforts by utilizing machines. The work can progress faster depending on how much sophisticated resources are used depending on the number of elements that are pre-designed properly.
While in cast-in-situ construction there is a significant need for manual work, which is a time-consuming and is subjected to waste in man-hours. This waste could be due to weather, less site supervision, more iterative details in the reinforcement drawings which need request for information. The evidence for that was the result of activity analysis which has indicated that approximately 60 % of the activities were the non-value-added activities. 15 % had been measured as support work for being semi-productive which did not really add any visible value to the reinforced square meter. Thus, non-value-added work equalled to 75 % waste in p-hours work and the rest of 25 % in construction time has only added value on the work.

The differences between Josephson's targeted projects index result which was 17,5 % as value added activities and this researches case study which was 25 % could be the size and number of the activities. Josephson's research indexes were based on multiple activities involved in the entire body of many targeted projects when the possibilities are very high to expose the workforce for task substitution between multiple tasks. Switching between many tasks would result into wasting more construction time instead of adding value due to moving back and forth for the labourers. While this research´s index result specifically relied on one single activity of reinforcement which covered on only Fallskärmen project. Therefore, the scope for losing construction time by the labourers to change their positions and be replaced with others was very much limited. In additional of that there were no any other simultaneous tasks to run parallel with reinforcement to make them switch over onto another tasks and waste time with this substitution. Therefore, the resulted index of 25 % for value adding work in this research was a little bit higher than Jossephssons index given in the theory. This was due to saving time in labourer's relocation.

The higher the number of simultaneous activities that are taking place at the same time, the higher is the possibility for waste of time by laborers. This could be due to issues encountered in waiting for materials due to logistical issues and material delays. As Josephson's indexes covered many activities running at the same time to overall

projects his non-value index was lower compared with this research's index which involved only one task.
With the introduction of work sampling method in the thesis it was possible to identify the specific activities that were responsible for the decline in labour productivity. The observations made it clear how commitment of laborers and availability of equipment played a pivotal role on labour productivity level on the construction site on any given day.

Using of MS Power project as planning software here was not fit for expanding the scope of options and features available in comparison to other software which were considered far more advanced. The MS project clearly lacks functions that could envision the enhancement of labour and material usage on site. There is no possibility for materials tracking because the software lacks information transfer between the material suppliers.  This software is a good tool to set up a proper and regular plan for task execution but still cannot resolve and manage the unpredictable risks which are exposed throughout the project´s time span.

# 6 Recommendations/Contribution

The research has contributed into providing some recommendations and management strategies for the future projects to improve the workforce productivity. This improvement focuses on two broad trends of proposing technological solutions and complying with a better management practice which resulted from implementing the Work Sampling method. The management includes setting up a proper Work Breakdown Structure to assign the right person for the right task on the right time as structured in the following table:

## 6.1 Planning & Management improvement recommendations

The following strategy was to mitigate the risks related to mismanagement of resources and actions to be taken to save construction time with assigning the right person for the right task.

*Table 6.1 Improvement plan to increase workforce productivity*

*Source: The table is own elaboration by this research author themselves.*

| Activity indicator | Potential % of wasting time | Improvement strategy | Actions | Reason to mitigate | Person responsible in WBS |
|---|---|---|---|---|---|
| **Travel time for material (material movement)** | 04 % | Validate the need for minimizing the material movement | *Generate material request in advance so that the correct material arrives when they are needed. | Improper storing material adjacent to the worksite | The Supervisor should complete the material request and determine the deadline for the request |
| **equipment movement** | 10 % | Equipment tracking | *Get a tool room onsite as tool boxes onsite. *Develop new fabrication area | Longer access & distance to equipment storage | Site engineer has to follow up & undertake back and forth of equipment |
| **Equipment setup** | 09 % | Preparation work | Equipment maintenance &better service support | *Adjust equip a day before & prior operation. * late start up | The foremen is responsible and delegated to this task |

| | | | | | |
|---|---|---|---|---|---|
| **Instruction taking** | 05 % | Better planning to reduce need for additional supervisor instruction | *Implement a daily meeting at the end or before the working day. *Increase available work front. | Hard access for the structural drawings | * assign supervisor for the knowledge transfer |
| **Waiting time for material arrival** | 06 % | *Better coordination for material support<br><br>* Material tracking | *Utilizing Head Mounted Device *faster crane to ease material transport | miscommunication with the crane driver | *Assign the site manager to follow prior deadline |
| **Preparation work/scaffolding** | 08 % | Optimum planning | Plan & prepare the tools time ahead | Delay in planning &preparing scaffolding tools | *Site manager planning prior task start |
| **discussion** | 04 % | working environment to adapt | provide frequent break | fatigue condition | supervisor to arrange break times |
| **Travel empty handed** | 03 % | APD Workplace outline plan | arrangement of site layout | avoid congestion | *Site manager to supervise |

## 6.2 Frequent Planning Check

Frequent and intensive check of the time schedule is needed in order to keep track on the right level of productivity by comparing the actual time of a particular activity has lasted to the time it was projected or scheduled to last. As all tasks are inter-dependent on each other the sequence of activities should be well organized ahead in a way that they do not hamper the work, and do not cause rework. Those activities which should be frequently reviewed are balcony mounting, inner walls, outer walls and concrete slab flooring prior the main slab commenced for casting.

## 6.3 Schedule Acceleration

The empirical validation has indicated that the time schedule could be accelerated by speeding up certain activities to increase productivity. This action depends on which stage the project has reached and where exactly the activity was contemporary to be accelerated. For example, during the finishing work where the indoor working circumstance was more convenient and easy-going, extra laborers can be borrowed from another company´s site to help. Botrygg has multiple sites in the city and it moves workers around in case of urgent demand and work overload on a specific project.

## 6.4 Intensive Site Supervision

Intensive site supervision was a significant success factors to avoid rework by putting right elements in the right places. For example, by putting right plumbing components in place, too much re-working hours spent unnecessarily to correct installation errors in the slabs can be avoided. This practice would protect the site manager to adhere with the initial schedule and avoid overload the existing laborers for an extra work stress. For example, in case of installing wrong plumbing components in the slabs, the concrete should be crashed in order.

## 6.5 Risk Management

According to the site manager risk management was an integral part of any project. Project risks regarding unpredictable issues can be managed through having a knowledge from previous projects. Those risks might be materials types to predict how the site layout sounds for fitting those materials in and which task has a higher priority to start with. As easy access for materials plays a vital role for mitigating the unforeseen risk of delay.

A preparation plan to be done to minimize the future unpredictable risks that would probably encountered. For example, arrangements must be done as material tracking in searching for material elements one week prior the precast assembly starts for mounting. Since materials delay was a great risk which cannot be predicted previously even though there is a proper planning, this action was regarded as an appropriate management.

Bad weather condition also was one of those unpredictable risks and an urgent circumstance which needed making a contingency plan to employ laborers on other simultaneous tasks. This risk for work interruption can be executed when using of crane for mounting of balconies would be unsafe during a heavy storm weather.

## 6.6 Incentive

Providing an incentive will motivate laborers to attempt upgrading their skill and reduce their excessive efforts need for achieving the same amount of work with a minimum number of hours. It develops a competitive advantage to improve their level of performance. This system generates a confidence and brings a good impression that the employer has taken the laborers´ expectation into account which creates a high work motivation.

### 6.6.1 Effective Sharing of Labour Skills

Effective sharing of labour skills can help to mitigate the human factors. Employing skilled labours on a specific activity which corresponds with their field of proficiency is regarded to be a success factor to increase productivity. This labour employment strategy of skills sharing from the experienced to unskilled could be included earlier in Botrygg´s procurement policy. This policy aims to increase the learning practice to share and transfer their knowledge with the new upcoming laborers. Mixing of skilled ones to interact with the new unskilled labourers could be a demand to have new experienced laborers in future. They can be employed on those tasks which require high skills when this need arises in the future.  For example, when the schedule falls behind the schedule, it will be difficult for the structural and reinforcement laborers to work as scaffolding laborers, if there has not been any skills sharing previously.

## 6.7 Request for Information (RFI) improvement

Information management is very critical for a project's success. In this section few improvement strategies are discussed depending on the feedback from the site manager.

### 6.7.1 Knowledge transfer

The transfer of knowledge was considered as a proceeding step towards more productivity enhancement from Botrygg´s previous workers experiments to the new labourers of similar sites. For example, all the site defects, mistakes and safety breaching which have deteriorated the workforce´s site performance would be noted so as to avoid repeating same mistakes in the new projects. This can be taught from the company´s workers´ past experience to their new co-workers. This transfer can be achieved at the end of each project in writing an experience feedback and reversal report. All the project´s engaged actors can discuss what issues have faced and how the consequences have been mitigated. For instance, defects in the walls technical specification arose when a certain wall became 10 cm wider than its origin design specification, so the concrete receipt must be modified and innovated so as to avoid happening this mistake newly again in the future projects (Hogar Lak,2017)[8]

### 6.7.2 Easier Access for Information

Easy access for information can be a success factors to improve production units. Access for a detailed structural drawing on site for smooth flowing of information to laborers and availability of a virtual model. This model can provide a better and more evident understanding how the production units will look like. Another access is a continuous attendance of the native speaker supervisor on site to pass a correct instruction is regarded to be the easiest access for information sharing with the Romanian laborers.

## 6.8 Design improvement

The design incompatibility was a major concern in Fallskärmen project. If a project has to be a success its critical for the issues affecting productivity to be rectified and improved. This section has improvements that can be applied on a day today basis.

### 6.8.1 Buildability in design

Practicing buildability to improve the design by creating of a virtual reality model for the project´s completed image to show how the building product would look like after constructing the design. This virtual model will improve the quality and provide a simple character for the design documentation. It provides an evident character to show how the building product would look like to target and fulfil the customer's request. As Botrygg is an independent client their focus could be on a simple design to complete the work without being exposed to design complexity. This can be achieved by simplifying and repeating the same design with the similar type of previously tested design attributes.

[8] Fallskärmen residential project site manager Hogar Lak ,2017

### 6.8.2 Design Management

Regular meetings by the contractor with the design team are recommended prior the documents become contemporary for the construction. Two weeks in advance prior the design handover to the contractor a meeting can be held in order to ensure and adapt the design documents to be compatible with the site condition. All multi-disciplinary drawings can be conformed and compared with the original structural design for adjustment and finding the clashes. The aim of these meetings is saving time to avoid requesting for information and ensure that an efficient constructability and buildability are achieved.

## 6.9 Weather Issues

Construction sites often have hindrances caused due to weather conditions. Every region has its own challenges with regarding weather in the construction industry. This solution can function by setting up a temporary plastic tent around the work site when the work is on the foundation stage and indoor work is not possible. Scaffolding materials can be used for building the tent around the construction area which can make the cost of making the tent negligible.

## 6.10 Construction Method Improvement

With the advancement of research in the construction industry. New methods of construction are bound to come forward which can significantly help to reduce construction time as.

### 6.10.1 Precast Construction Method

Adopting the Just-in-time production model of construction has contributed that the precast construction model became a source of efficiency both for the p-hours and the size of unit areas produced. This is a monopolized strategy is adopted by majority of the construction companies including Botrygg. This method can provide many advantageous because of it´s easier workability with elements and achieving a faster installation process. All plumbing installations are pre-installed by the manufacturer and any defects in the components would be returned back to manufacturer to be dealt with. The site manager indicated that this method reduces both labour efforts and charges by 50 % faster than the cast on site but it is more subjected to unpredictable material delays. Therefore, apparently, it became clearer to emphasize that this method has a potential impulse to enhance project´s productivity from the time factor perspective.

## 6.11 Technological Improvements

These following technological alternative solutions have been used to keep the track on efficiency and improve project´s productivity through the project´s management perspective as detailed below:

### 6.11.1 **Wireless communication**

The workers on the site have issues with communication. They were seen walking every now and then towards the supervisor or to the other laborers to get instruction or advice in most cases while the work was going on. This scenario of moving and leaving their position accumulates as a huge amount of wasting time and decreasing the productivity. This can be decreased if all the workers working on the site are connected by a radio or wireless link which makes communication easier and faster. The workers will not need to leave the station and the supervisor can attend to more queries in shorter time.

### 6.11.2 **Drones for site inspection**

The construction site has constant work going on which was hard for the supervisor to be everywhere to monitor and check the work. Using drones to inspect the site can help the people who are not on site to keep a track on the work, As well as the safety inspector would have a clear picture if people working in different levels are following safety protocols. This facility can provide a larger visuals area for the management staff and would covers other activities which are executed simultaneously alongside with others. It would help for a better control and supervision and saves much time for supervisor's efficient productivity.

### 6.11.3 **Self-Compacting Concrete**

Self-compacting concrete type is another technological solution which can be utilized in this project in order to boost for an easier handling and processing with concrete. This concrete is a mixture of concrete yogurt and water which makes faster to be handled in processed compared with the rough conventional concrete. This option increases easier placement, better workability with and saves labour time. Based on site managers previous experiences this concrete saves about 1 labour per working with 20 % of vibrating and compacting charges in the slabs. Even though it is expensive but it worth to be used on site.
An example for advantageous was noticed that plastering of outside wall surfaces goes faster and easier with a minimum charge. Likewise, it added value for their building products. It provided a better quality and durability of the foundation´s external outer façade walls due to its homogeneity characteristics.

### 6.11.4 **BIM Use**

Meanwhile as noticed the software used by Botrygg does not integrate all the involved actors in the project during all phases towards a collaborative system. Therefore, using BIM for planning and scheduling is regarded to be an optimum tool to be used. Using of 3D model with adding the 4th model of the time function tool is an effective factor to integrate the planning system together and engage the material suppliers in the construction process. This tool can help the tracking for materials and avoid logistical delay issues. In additional of that it´s a more advanced software to do the project´s quantity take-off and estimate labour crew size and charges. Thus, the site manager is not obliged to manually plan out the activities for the upcoming week as he was doing it with MS power project software with Botrygg.

# 7 Conclusion

Labour productivity is one of the key topics in the construction industry. The success and failure of a project is directly dependent on how the labour force is managed by a firm. The purpose of the thesis was to study and analyse labour productivity. Also, to recommend effective solutions to the site managers for mitigating those impacting factors that could improve the labour productivity.

Implementing the benchmarking methodology of measurement model on Botryggs targeted projects has shown a significant decline within the workforce´s construction work. Measuring those projects WH/m2 of baseline productivity attribute in reinforcement tasks has concluded a remarkable variation in their labour productivity. Two of projects are still ongoing alongside each other while Fallskärmen was nearly finished. This result has been reached through comparing all three projects attributes as follows:

| Project no | Project name | Baseline productivity metrics wh/m2 BP | Performance ratio PR=CP/BP | Cumulative productivity CP= total wh/totalm2 | Project Management Index PMI=(CP-BP)/BP |
|---|---|---|---|---|---|
| 1 | Tyresö | 0,65 | 1 | 0.65 | 0.0 |
| 2 | Övre Vasastaden | 0,95 | 1.28 | 1.2 | 0.28 |
| 3 | Fallskärmen | 1,06 | 1.4 | 1.5 | 0.4 |

Tyresö project has experienced the best labour performance with the lowest baseline productivity and project management indexes. While Fallskärmen. has experienced the worst labour productivity due to its highest baseline productivity and poor management indexes. This conclusion was explained in the figure 4.2 in the empirical part.
The activity analysis conducted on Fallskärmen project site to detect shortages in the management practice has found an explicit and evident indication for this productivity decline. It concluded that 75 % of the total task time was engaged in non-value-added work. While about 25 % of the total time was regarded as value added construction work. Those management gaps which were detected and responsible for this low rate of productivity in reinforcement task were as follows:

- Wasting time by moving on site without any productive activity
- material & equipment movement
- waiting for material arrival

Many factors which have impacted on lower labour productivity were found through interviews with the Fallskärmen site manager and site visits. Those responsible factors which were illuminated involve two stages of pre-construction and construction stage.
In pre-construction, the design incompatibility with the site condition has influenced on laborers. They became involved in too much rework done due to lack of coordination between the site manager and the design team. There was no clear vision of the design specification to the site condition. The process of design adaptability to make the drawings be buildable with a right design was hard to be managed. The mismatching

of stairs design with the building structure was one of those examples. This issue was hard to be resolved which resulted into too much waste of the construction time due to work interruption.

The improper planning software of MS Power project which lacked communication with the suppliers in tracking for materials was the major impacting factors. This tool lacks the function of material tracking which influenced negatively to interrupt the construction work and delayed the tasks execution.

Ground data condition of upcoming water pressure required a design of a stronger reinforcement structure for the foundation which resulted into much rework and delay. While during construction, the major factors were the planning management practice of intensive supervision.

The request for information (RFI)in searching for the right design intent by the contractor led into doing much rework. Especially in cast-on-site construction method in casting the slabs this issue repeats frequently and involve mistakes of installation errors which requires concrete crashing and waste time.

Since greater investment in sophisticated equipment was an extra cost burden on Botrygg ,therefore the company is not investing too much in this sector. This issue has made the project manager to be enforced to substitute the machinery work with the human efforts to catch up with the schedule. Material delivery was a problem due to adopting the just-on-time construction method .This issue has led to storing material as reserve to skip waiting for material delivery on time which costed extra burden and extra work on the laborers.

New procurement contract in every new project was another factor to restrict Botrygg in sharing of labour skills. Botrygg employed new laborers in every new running project which minimized the possibility of skills sharing and knowledge transfer from the most experienced to the unskilled ones. This procurement policy prevented Botrygg from having permanent employees to utilize experience they gain throughout their employment period in future projects.

Based on the factor analysis, some technological and managerial aspects, which would increase the work flow as need for buildability have been concluded. Experience taking from similar past projects have been proposed. Solutions such as creating a better virtual reality model can work efficiently to display the final version of the building product for Botrygg. Using of BIM as 3D model by adding the 4D of time function will help the site manager and sub-contractors. This function tackles the conflicts better and have closer communication in material delivery on time. The usage of drones on site will reduce time and can be very fruitful in monitoring safety and work progress.

The managerial recommendations included organizing design meetings between the site manager and the design team to resolve the clashes. Assigning a well secured Work Breakdown Structure (WBS) prior to deadline of each activity finishing and starting.

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