Labour Productivity Measurement method using 3D BIM of a Commercial Project

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Abstract - *Knowledge of labour productivity is essential for cost estimation and progress control. Current advances in 3D Building Information Modelling (BIM) applications have allowed for the practical development of BIM-based visual progress control systems. It is estimated that, around 25-30% of concreting cost is for formwork & requires about 60 % of time in construction. Hence, it is necessary to determine labour productivity associated with formwork. The goal of this thesis is to explore the importance of labour productivity data for measuring compound progress. Therefore, this paper develops a field labour productivity data acquisition method by integrating a 3D model with associated information. To evaluate the productivity rates of labours for formwork, relevant code along with past data was considered. Comparison between the actual productivity and planned productivity, using these productivity rates were done and the information was recorded graphically. Minimum future productivity percentage of the building was then determined.*

***Key Words*: Building information modelling, Quantity takeoff, Labour productivity, Structural formwork**

1. INTRODUCTION

Productivity is an important aspect of construction industry that may be used as an index for efficiency of production. Efficient management of construction resources can lead to higher productivity which can help to achieve cost and time saving. Construction is labour oriented industry. It heavily relies on the skills of its workforce. The labour is industry's most valuable asset. It is important to improve efficiency of production by improving productivity of labour. The most common approach for productivity estimation is to use the past data from similar projects as a baseline for new projects.

In all industries, labour productivity is considered to be one of the best indicators of production efficiency. The construction industry is related with a lot of activities, as a result of which, labours are required. As and when new technologies are introduced, more activities are being labour extensive, except in the case of formwork placement. It is estimated that, around 25-30% of concreting cost is for formwork & requires about 60% of time in construction. Hence, it is necessary to determine labour productivity associated with formwork.

Formworks are tools and dies of concrete which gives desired shape, size and control its position and alignment. They also carry weight of freshly placed concrete and itself besides live load due to materials, equipment and workmen. Economy, quality and safety are the three main objectives targeted for formwork structures. It is essential to plan ahead and device a way where temporary structures are being used in the most cost-efficient way possible without having to sacrifice the quality and safety of the structure. Regardless of the type of formwork being used, it should have the capacity to carry a heavy load without losing its shape and rigidity. There are different types of materials used for formworks. In the early years, lumber or timber was widely used as temporary structures in construction. Nowadays, materials such as plywood, steel, plastic, fibre glass and precast concrete are being used.

Labour productivity associated with formwork is measured using 3 dimensional BIM modelling. Building Information Modelling or BIM, is a digital representation of the building process to facilitate the exchange and interoperability of information in a digital format.

Eastman also describes six important applications of BIM that apply to contractors as follows.

- Clash detection
- Quantity takeoff and cost estimation
- Construction analysis and planning
- Integration with cost and schedule control and other management functions
- Offsite fabrication
- Verification, guidance and tracking of construction activities

BIM has many advantages, but its key role is to facilitate mutual understanding and communication. It is essential to identify the well-defined properties of a 3D model and to establish a database structure pertaining to a specific object for the successful application of BIM. BIM facilitates communication with 3D visual drawings and progress representation with associated data among the owner, architects, engineers and contractors. A 3D digital model differs from a geometric model in that it provides data on inherent properties. A geometric model is a solid model having only geometric dimensions. Therefore, a model containing only properties is a 3D object. Advances in BIM technologies have facilitated improvements in integrating diverse information during the planning phase. The main benefit of applying BIM-based tools to estimate the project is its use in material takeoff. Estimators can extract material quantities automatically from the BIM and use this information in downstream cost estimation application.

1.1 Productivity

Productivity has been generally defined as the ratio of outputs to inputs. Construction projects are mostly labour based with basic hand tools and equipment, as labour costs comprise 30 % to 50 % of overall project cost. There are many factors that influence the productivity in construction industry. Labour productivity is one of the most important factors that affect the physical progress of any construction project. Construction labourers are responsible to operate a variety of equipment. To perform their jobs effectively, construction labourers must be familiar with the duties of other craft workers and with the materials, tools, and machinery they use. In India, one of the greatest challenging faced by the construction industry is to attract and to attain skilled labour. Low productivity among the labour will give impacts to the construction industry such as cost overruns and schedule delays.

1.2 What is Labour Productivity?

Productivity can be defined in many ways. In construction, productivity is usually taken to mean labour productivity, that is, units of work placed or produced per man-hour. The inverse of labour productivity, man- hours per unit (unit rate), is also commonly used.

Productivity = Output/Labour input

1.3 Impacts of Labour Productivity in Construction Work

The construction process results in relatively high costs and labour becomes a more important input in the production phase. Moreover, the labour cost is somewhere between 20% and 50% of the total project cost and reduction of these costs can be best carried out by the productivity improvement. At the same time, the success of a construction company in today's competitive market largely depends on accurate estimation of productivity, and a reasonably correct assessment of the labour cost is fundamental to the accuracy of any estimate might be obtained. In addition, the effect of the factors on productivity may vary from task to task. Although some factors could have similar influences on the productivity of a number of tasks, their rate of impact on productivity may be different. There are some ways to overcome the bad impacts of labour productivity in construction industry:

(1) Increasing skills and experience of workforce

(2) Good management in construction work

(3) Improve motivation among the labour

(4) Reduce the lack of material availability

(5) Decrease the number of migrant labour

1.4 Use of Labour Productivity

Productivity is one of the key measure of construction performance. It was observed by Kaming and Olomolaiye that poor productivity of construction craftsmen is one of the most daunting human resource problems in developing countries. Labour productivity rates are used as indicators of the construction time performance. They are used in planning and scheduling of construction, controlling of the cost and worker performance, estimating and accounting. If a company wishes to reduce risk, increase profits, or gain market share, there is direct need within the firm to have accuracy data on and use of labour productivity. Although studies have been made in a number of countries, most of the data available is not directly relevant to all countries because of the differences in materials used, techniques adopted and working environment. Construction workers too have differences in the work culture.

1.5 Methods of Obtaining Labour Productivity

Before productivity can be increased, there is need to measure and quantify the existing situation. Lord Kelvin's dictum 'to know properly you must measure it' is sound advice to anybody interested in measuring productivity. The measure of construction productivity is thus a very important issue.

There are two different methods of generating data on productivity – accountancy based and engineering based methods. Accountancy based standards rely on the analysis of historical accounting data to establish work hour requirements for specific types of work. Engineering based standards involve breaking down complex work processes into small manageable parts and analyzing these parts for the length of time required to complete these processes. The accountancy-based data are relatively easy to follow but they do not capture the varying working conditions. The engineering methods of measuring labour productivity include work measurement, work sampling, time and motion analysis, and modelling. Work measurement is the determination of the time required for an average operative to carry out a particular task in accordance with a specified method and standard of performance. Work sampling involves observing individual pieces of the work process and classifying the results as either productive or non-productive. It is useful for recording productivity levels for comparative purposes. Time and motion studies are said to be the most accurate methods for generating productivity standards. Factor based modelling is arguably the most applicable engineering-based technique to the construction industry and has the potential to produce useful data.

2. BIM-ASSISTED DAILY PRODUCTIVITY MEASURING SYSTEM

2.1 Concept & Approach

Scheduling control in construction projects is limited to a pure time schedule based on master planning, which is primarily dependent upon the experience and intuition of the subcontractor's manager. Scheduling based on labour productivity is not practiced in building construction projects due to insufficient productivity data and a lack of appropriate data collection methods. For example, the amount of manpower for formwork is decided based on its influence on the following task (concrete pouring) and/or the allocated budget.

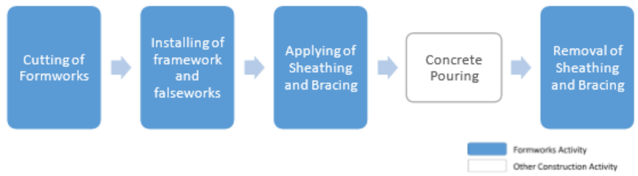

Fig-1: Sequence of Activities involved in formworks

Intuitive and empirical decisions can have adverse effects on time management. Therefore, manpower planning is done by using the past records of similar projects, as well as referring to the labour code, Indian Standard, IS:7272, "Recommendation for Labour Output Constants for Building Work", to measure the productivity rates. The standard estimate becomes a baseline for public project estimation. However, in addition to different material types, labour costs for formwork, in practice, are calculated separately considering the location, including the substructure, superstructure, and ancillary facilities. Applicability of the standard estimate is limited to normal situations due to the difference in the level of detail. Therefore, a new approach to control of daily-in-house productivity information using the standard estimate as a reference is needed. Baseline productivity data is required to obtain accurate productivity data.

2.2 Labour Productivity Rate

In computing of the productivity rate, the amount of physical output per man-hour is measured. It indicates that the worker is more productive when he is producing more output within an hour of work and it is measured in terms of area.

2.3 Construction Progress Measure & Labour Productivity

Project control analyzes the variance between the actual status and the planned target. The status is normally expressed in terms of progress, which is used to describe the work performed in terms of the percentage of work completed in a designated time period. Thus, the progress measure is composed of cost and time factors. It is crucial to integrate time with cost in order to accurately calculate progress. Therefore, this thesis uses an Indian Standard, IS: 7272-Part 2, "Recommendation for Labour Output Constants for Building Work", to measure the progress of labour productivity with respect to productivity rates. The primary concept of the BIM-based daily productivity, progress monitoring, and control systems is to acquire daily information using 3D objects and to enter it into related databases.

The process is carried out as follows:

1) Preparing 3D model of a commercial building.
2) Extract quantities using 3D model.
3) Establish a standard productivity based on relevant IS Codes and labour data.
4) Measure and report daily input labourers and work volume.
5) Compare actual and planned productivity and progress.
6) Record the productivity and progress in the database.

2.4 Baseline for Productivity

Productivity standards and a standardized method of quantity measurement need to be established for the measurement of daily progress. This thesis analyzed the labour input per unit from Indian Standard IS: 7272-Part 2.

At present different departments at a place are having their own schedule of rates. A comparison of the labour and material constants used for different items of work in these schedules of rates has indicated that there is a good variation in them and due to which different rates exist in various departments for the same items of work in the same locality. This standard is being issued in order to rationalize the labour output constants for different building works.

The labour constants have been arrived at by the Central Building Research Institute, by taking actual observations, using work measurement techniques, on the construction sites. Different types of building works up to 10 m height of CPWD, MES and other organizations were included where the workers from neighbouring states were working. Sufficient number of observations to ensure a confidence limit of 95 percent and an accuracy of ±5 percent were taken. The relaxation allowance for the time required for rest to overcome physical fatigue and working condition allowance has been taken as per the standardized values given for Indian conditions by the Ministry of Labour, Employment and Rehabilitation, Government of India

Table-1: Productivity rates of labours for formwork

ITEM	STANDARD PRODUCTIVITY Man-day/ m^2	PRODUCTIVITY m^2/Man-day
Rectangular column/ walls	0.45	2.22
Suspended floors/roofs	0.43	2.32
Sides & soffits of beams	0.5	2

The above values are the productivity standards taken into account along with the past labour report data, for measuring the labour productivity. These values are the combined rates for carpenters and mazdoor (helper).

Productivity is calculated using basic labour data. A crew team for formwork is composed of carpenters and labourers. There is no significant impact from an individual's performance, whereas the crew team's performance is crucial for analyzing the productivity. Therefore, this thesis considers the productivity of a crew team based on the proportion of labour costs. The combined productivity rate becomes a baseline for planning the schedule and cost. Progress monitoring and control are also based on this baseline.

3. PRODUCTIVITY ANALYSIS

3.1 A Case Study

Although a great number of publications exist concerning construction productivity, there is no agreement on a standard productivity measurement system. Researchers have concluded that it is difficult to obtain a standard method to measure labour productivity because of project complexity and the unique characteristics of construction projects. The uniqueness and non-repetitive operations of construction projects make it difficult to develop a standard productivity definition and measure.

In order to arrive at a reliable productivity rate, productivity analysis for 10 projects was studied. Table 5.1 below specifies the productivity rates for buildings.

Table-2: Productivity Analysis Result

BUILDING	COLUMN	BEAM	FLOOR
1.196	0.394	0.468	0.334
2.535	0.78	1.17	0.585
0.942	0.292	0.39	0.26
1.366	0.42	0.63	0.316
2.054	0.696	0.836	0.522
2.254	0.714	1.027	0.513
0.809	0.273	0.341	0.195
2.322	0.633	1.267	0.422
3.493	1.161	1.221	1.11
2.758	0.923	0.998	0.873
Average	0.6286	0.8348	0.513

The productivity rates which is obtained from the code, Indian Standard, IS: 7272-Part 2, "Recommendation for Labour Output Constants for Building Work", and the productivity analysis results of 10 projects, the final standard for productivity rate is achieved, which is taken into consideration for obtaining the projected productivity for the building.

4. 3D BIM-BASED QUANTITY TAKEOFF

Quantity takeoff is typically conducted manually with the assistance of a computer program using 2D CAD drawings. The first task in daily progress measurement is to break down the work into a micro-manageable level. Quantity takeoff is then conducted using the algorithm established in the 3D BIM model. 3D BIM-based quantity takeoff has the advantage of automatic calculations based on a hierarchical breakdown and the flexible application of design changes. The amount of concrete for a girder is calculated based on measurements of the length and the section outer length. There is one significant calculation difference in that the BIM-based quantity takeoff includes the girder with the contacted slab floor. It is necessary to prioritize inclusions in the extraction of quantities for overlaid parts.

4.1 Actual Volume of Work Performed Using BIM Takeoff

2 D Based Calculation Formula

Slab = W_{s1}x W_{s2}

Beam = L_G x h_G x 2

Column = (W_G + W_{C2}) x 2 x H

BIM Based calculation Formula

Slab = W_{s1}x W_{s2}

Beam = L_G x (h_G - t_s) x 2

Column = (W_G + W_{C2}) x 2 x (H- t_s)

Where,

H = Height of story; L_w = Length of wall; W_s = Width of slab

T_s = thickness of slab; W_c = Width of column; L_c = Length of girder; h_G = Height of girder

The quantity of formwork is extracted based on attributes of structural components. The tasks for extracting the element information are as follows.

- Divide the BIM model into structural components in different levels.
- Insert the component information for the selected level.
- Extract the required information using the Schedule/Quantity function.
- Export the extracted information to Excel to sort, calculate, and report.

4.2 Productivity Calculation

The quantity for an individual object is explained with attributes. The daily expected work volume is calculated using the amount of manpower and the standard productivity rate, whereas the actual volume of work performed is measured using the BIM take-off. The daily productivity rate is then calculated by dividing the work volume by the amount of manpower. The achievement rate is simply calculated as the work performed divided by the work planned.

Expected Work Volume = No: of members x Productivity

Daily Productivity = Work volume / Man power

Achievement Rate = Work performed / Work planned

Daily productivity data can be analyzed for each building, sub- structure/superstructure, and crew team. The monthly productivity on the superstructure is significantly higher than the baseline; on the other hand, the substructure monthly productivity is lower than the baseline. An analysis of productivity for the superstructure shows an increasing learning effect curve due to repetitive work. Progress can be analyzed, and accurate planning of the remaining work is possible using productivity analysis results.

4.3 3d Modelling of a Commercial Project using BIM

A 3 storied commercial building, situated at Calicut, of area 3232.3 sq. ft was modelled using Revit 2017 which is shown in the figure 2.

Quantities were extracted using this 3D model and an integrated break down structure. They are divided into beams, columns, and slab and information regarding each of these elements were obtained using the software. Combined productivity rates for these members were taken and the volume of work, both expected and actual, was determined.

Since the project is an on-going one, the number of crews at site was recorded in order to get the actual productivity. Projected productivity was calculated based on the calculated number of crews using the combined productivity. Graphs showing variation between actual productivity & projected productivity was developed.

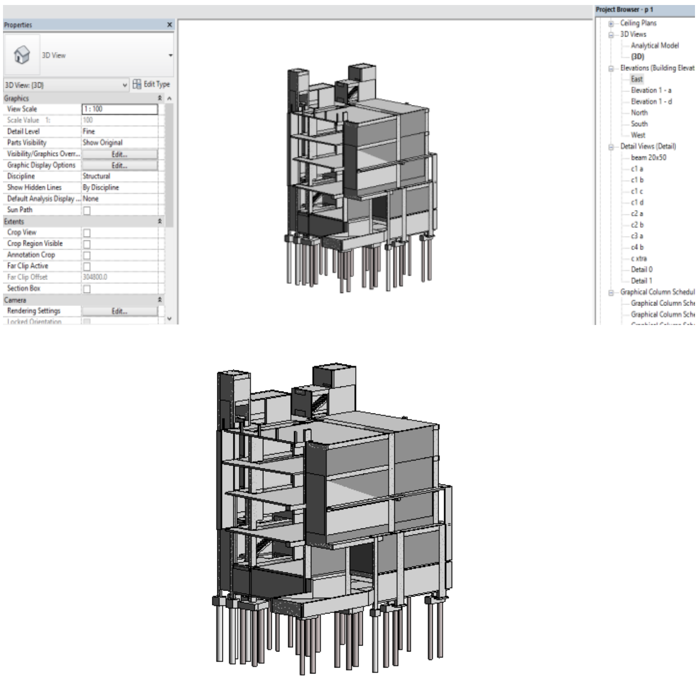

Fig-2: 3D Model in BIM

These values of actual productivity & projected productivity of these structural members were integrated in order to get the productivity analysis of the building.

BEAM

Table-3: Actual Productivity

Reference Level	Length m	Height m	Area m^2	No: of member on site	Standard productivity (as per code)	Consolidated productivity	Productivity m^2/man-day	Expected work volume	Actual work volume	Actual productivity
cellar	6.17	0.45	5.553	4	2	1.48	3.48	13.92	22.212	1.38
cellar	3.813	0.4	3.0504	4	2	1.48	3.48	10.44	12.2016	0.76
cellar	4.382	0.4	3.5056	3	2	1.48	3.48	10.44	10.5168	1.168
cellar	2.435	0.4	1.948	3	2	1.48	3.48	6.96	5.844	0.649
cellar	1.52	0.4	1.216	3	2	1.48	3.48	3.48	3.648	0.405
cellar	3.2	0.4	2.56	3	2	1.48	3.48	6.96	7.68	0.85

Table-4: Planned Productivity

Reference Level	Length m	Height m	Area m^2	No: of Members required	Standard productivity (as per code)	Consolidated productivity	Productivity m^2/man-day	Expected work volume	Actual work volume	Actual No: of crew	Planned Productivity
cellar	6.17	0.45	5.553	4	2	1.48	3.48	13.92	22.212	4	3.96
cellar	3.813	0.4	3.0504	3	2	1.48	3.48	10.44	12.2016	4	2.17
cellar	4.382	0.4	3.5056	3	2	1.48	3.48	10.44	10.5168	3	2.5
cellar	2.435	0.4	1.948	2	2	1.48	3.48	6.96	5.844	3	1.38
cellar	1.52	0.4	1.216	1	2	1.48	3.48	3.48	3.648	2	0.86
cellar	3.2	0.4	2.56	2	2	1.48	3.48	6.96	7.68	3	1.82
cellar	3.893	0.4	3.1144	3	2	1.48	3.48	10.44	12.4576	4	2.22
cellar	4.103	0.4	3.2824	3	2	1.48	3.48	10.44	13.1296	4	2.34
cellar	3.64	0.4	2.912	2	2	1.48	3.48	6.96	8.736	3	2.07
cellar	3.785	0.4	3.028	2	2	1.48	3.48	6.96	6.056	3	2.15

The above table indicates some of the values of beam extracted from BIM. Actual productivity is calculated based on the number of workers on site, whereas the planned productivity is calculated based on the actual number of workers in accordance with the productivity derived from standard productivity from IS code and past productivity data. Similarly, the actual and the planned productivity for columns, and floors are obtained and are plotted graphically.

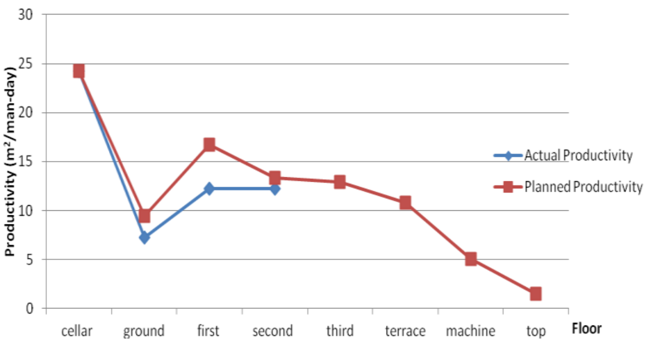

Fig-3: Productivity Analysis for beam

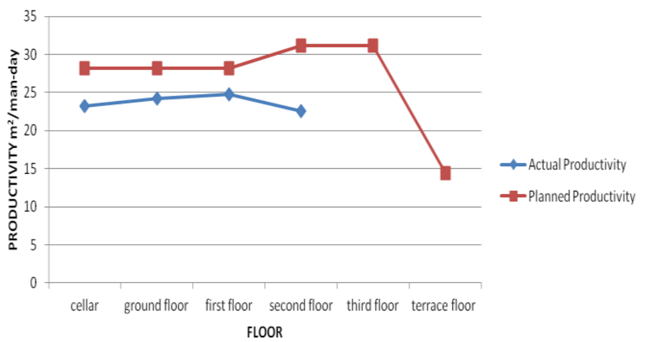

Fig-4: Productivity Analysis for Structural Column

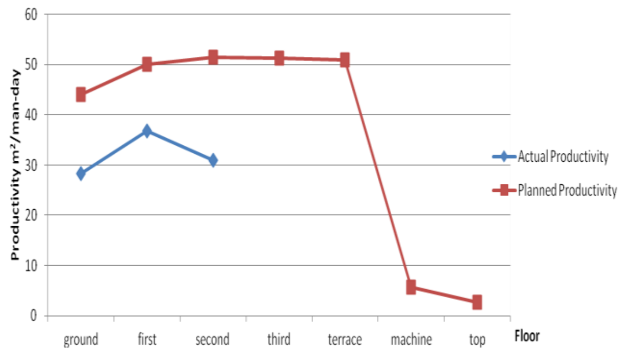

Fig-5: Productivity Analysis for Floor

4.4 Building Productivity

The combined productivity of actual and planned, of each level of the building is determined and is shown in table

Table-5: Combined Productivity

	BEAM		COLUMN		FLOOR		COMBINED	
	Actual Productivity	Planned Productivity	Actual Productivity	Planned Productivity	Actual Productivity	Planned Productivity	Actual Productivity	Planned Productivity
cellar	24.27	24.25	23.25	28.223	-	-	23.76	24.26
ground	7.27	9.44	24.25	28.223	28.24	44.07	25.19	27.24
first	12.26	16.69	24.74	28.223	36.83	50.104	29.03	31.67
second	12.212	13.308	22.62	31.12	30.98	51.54	28.79	31.98
third		12.882		31.122		51.23		31.74
terrace		10.81		14.384		50.913		25.369
machine		5.008				5.59		5.299
top		1.5				2.6		2.05

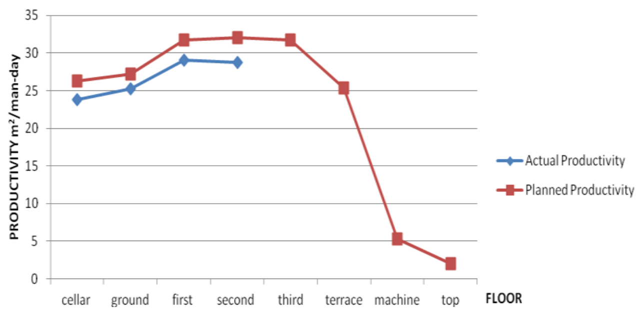

Fig-6: Productivity Analysis for building

5. RESULT ANALYSIS

5.1 Beams

For beams, the productivity rate is low as it requires more number of labours compared to columns and slab. Expected work volume is kept as the base line for comparison. When actual work volume falls below expected work volume, number of labours is increased.

From the graph showing variation between actual and planned productivity, the maximum value for the future planned productivity is 13.308 m²/man-day and the average value of future projected productivity is 8.7 m²/man-day.

Hence the percentage difference between the highest planned productivity and the average value of future planned productivity is 41.87%, which indicates that the actual productivity should not fall below 41.87% of the future commencing work.

5.2 Columns

From the graph showing variation between actual and planned productivity for columns, the maximum value for the future planned productivity is 31.12 m²/man-day and the average value of future projected productivity is 25.54 m²/man-day.

Hence the percentage difference between the highest planned productivity and the average value of future planned productivity is 19.68%, which indicates that the actual productivity should not fall below 19.68% of the future commencing work.

5.3 Floors

From the graph showing variation between actual and planned productivity for floors, the maximum value for the future planned productivity is 51.54 m²/man-day and the average value of future projected productivity is 25.54 m²/man-day.

Hence the percentage difference between the highest planned productivity and the average value of future planned productivity is 45.56%, which indicates that the actual productivity should not fall below 45.56% of the future commencing work.

5.4 Building Productivity Analysis

From the graph showing variation between actual and planned productivity for building, the maximum value for the future planned productivity is 31.99 m²/man-day and the average value of future projected productivity is 19.28 m²/man-day.

Hence the percentage difference between the highest planned productivity and the average value of future planned productivity is 49.57%, which indicates that the actual productivity should not fall below 49.57% of the future commencing work.

6. CONCLUSION

Labour productivity is one of the most important factors that affect the physical progress of any construction project. Construction projects are mostly labour based with basic hand tools and equipment, as labour costs comprise 30% to 50% of overall projects cost. Since, the technology is developing, lot of works are becoming labour extensive, except in the case of formwork. Labour productivity of a commercial project was assessed by modelling it 3 dimensionally by using a software called BIM. A combined productivity rate was derived from standard productivity rate given in IS: 7272 Part 2 and past labour usage were used for determining expected work volume and actual work volume. The actual work volume was calculated by breaking down the structure into beams, columns and slab, by using BIM. The number of labours was increased when the actual work volume was below the expected. Project progress was monitored by comparing the actual daily productivity and the calculated productivity, which was obtained from BIM, was plotted graphically. The minimum percentage of future productivity was estimated from the productivity analysis graph of the building.

From this study, it is concluded that the actual productivity should not fall below

- 41.87% of planned productivity for beams
- 19.68% of planned productivity for columns
- 45.56% of planned productivity for floors
- 49.57% of planned productivity for building

7. LIMITATIONS

This study is limited to productivity analysis of superstructure and it was calculated from the combined productivity rates given in the IS code and past data. In the case of substructure, there is no available standard rate of labour productivity for formwork.

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