FACTORS AFFECTING PRODUCTIVITY AND FUNCTIONALITY OF PRECAST CONCRETE BUILDING CONSTRUCTION

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Abstract

The purpose of this study is to bring out the factors affecting labour productivity, which can have a strong influence on both time and cost of construction of precast concrete buildings in the developing world countries such as India. This paper also provides a brief discussion on some parameters affecting the functionality of precast concrete buildings. For identifying the 'wastes' in the processes and quantifying the shortcomings in the productivity, work sampling was conducted in five precast concrete construction (PCC) projects in India. Freewheeling, on-site interviews were conducted at the projects to find out the factors affecting productivity. The frequency and severity of the various parameters affecting the functionality of precast concrete buildings were obtained through a questionnaire survey. The work sampling analysis found that about 46% were NVA (Non-value adding) and NVAR (Non-value adding but required) activities, which adversely affected the productivity and that the process 'wastes' identified at erection sites were more than those in the production yards. The questionnaire survey on functionality revealed that 'non-conformance with tolerance limits for precast concrete elements' has 'high' frequency of occurrence and 'very high' severity and a field study found that about 40% of the precast panels failed to comply with tolerance limits. The reasons for 'wastes' in different trades viz. concreting, shuttering, reinforcement and erection in Indian PCC projects were analyzed in this paper which could help in understanding the reasons behind the prevailing low productivity. More importantly, this study also explores the parameters affecting the functionality of precast concrete buildings.

While the functionality issues identified may or may not be typical of the entire precasting industry, the wastage issues identified have been widely reported in literature as quite prevalent in the construction industry.

1. INTRODUCTION

Shortage of housing is one of the major issues that the world is facing today. The rapid increase in urban population coupled with the rapid urbanization has resulted in land shortage, housing shortage, congested transits, and has severely affected the basic amenities like water, power and open spaces in the cities (JLL, 2012). Though urbanization is a common phenomenon in most of the developing countries, the Indian scenario is quite different because of the sheer magnitude of its population, which is about 1.2 billion as per 2011 census (MoHA, 2011). During 2001-2011, the growth of urban population of India had compounded at an annual rate of 2.8%, resulting in increase in the level of urbanization from about 28% to 31%, which in turn led to a huge demand-supply gap in the housing sector (JLL, 2012). As projected by Cushman and Wakefield (2014), as of 2017, the combined urban and rural housing shortage in India would have been about 90 million. In the 12th five-year plan, the Indian Ministry of Housing estimated a housing shortage of about 20 million units in urban areas with 99% of those in the economically weaker sections (EWS) of the society, which requires the government to build houses that are 'affordable' enough for EWS (MoHUPA, 2012). Over the past few decades, the government has introduced many schemes to increase the housing supply. The latest scheme is the 'Housing For All by 2022' (MoHUPA, 2012). However, providing Affordable Housing (AH) is constrained due to many factors. The AH projects are becoming increasingly difficult due to the lack of land-parcels, lack of finance, rising input costs, congested transit routes, and regulatory hurdles (JLL, 2012). In addition, in most cases the traditional cast in-situ construction (CIC) mode leads to poor quality and slow construction – resulting in the failure of most housing schemes. Literature states that Indian projects are facing heavy schedule overruns (Ahsan and Gunawan, 2010) and Iyer and Jha (2005) reported that more than 40% of the projects

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in India have failed in schedule performance. Konka (2012) stated that lack of skilled workers and manpower in construction sites was identified to be the most important causes for delay of projects. If the industry still continues to depend on the manpower for construction then it would be difficult to meet the growing demand for housing in the country. Moving towards large scale mechanization and innovative construction methods like precast construction could be a feasible and viable solution.

1.1 Precast concrete technology in affordable housing sector

An efficient method for meeting the urgent demand in Indian housing sector would be using the precast concrete construction (PCC) technology. Richard (2005) stated that prefabrication in the construction industry is considered as the first level of industrialization. Besides speedy construction and better quality, a major advantage of PCC is the very large repetition of formwork when compared with the conventional CIC methodology, with consequent cost savings. Polat (2008) reported that 93 percent of contractors in the USA achieved cost savings when they adopted PCC. Studies (Gibb and Isack, 2003; Goodier and Gibb, 2007) found out substantial cost savings due to usage of PCC technology. The construction industry generates a huge quantity of Construction and Demolition (C&D) waste. From the case studies done by Jaillon and Poon (2009), the average waste reduction level was about 52% when adopting precast construction. In another study by Jaillon & Poon (2008), it was found that by implementing PCC the quality control can be improved. Also, there is a potential reduction in noise and dust pollution which generally are major contributors to pollution in the construction industry (Pons & Wadel, 2011). However, in spite of all these advantages for PCC, it is reported that only about 2% of the total market value for concrete construction in India is shared by PCC; whereas the remaining 98% is shared by CIC (Balakrishna, 2014). The Contractors' unawareness of significant advantages offered by PCC is one of the major attributes preventing the extensive use of precast systems in India (Das and Jha, 2011).

Research through the past two decades has revealed the major barriers for the growth of PCC as (i) high capital costs (Chiang et al., 2006; Zhang et al., 2014), (ii) lack of adequate road networks (Chaitanya, 2013; Balakrishna, 2014; Blismas et al., 2007), (iii) lack of steady demand for products to maintain the precasting yard at its optimum level (Thanoon et al., 2003), (iv) lack of involvement of smaller contractors (Rahman et al., 2006) and (v) jointing problems/quality issues (Chiang et al., 2006; Balakrishna, 2014). Apart from these, the authors believe that the learning cycle of PCC is high in a new project, which in-turn increases the floor-to-floor cycle time of the initial lower floors. Many countries have been successful in implementing PCC by overcoming these barriers to cater to the huge housing demands. Singapore has been using PCC for high rise building for the past 30 years (Thanoon et al., 2003). The PCC share in the housing sector in USA is about 30%. In former East Germany, 24% of housing is constructed using precast concrete; Finland uses 70% of its concrete production in PCC (Glass, 2000; Sacks et al., 2004; Thanoon et al., 2003). With the increasing housing demand in developing countries like India, there is a huge market for PCC in the near future.

2. RESEARCH SIGNIFICANCE

The adoption of PCC technology is a must for developing world to meet the huge demand for housing. However, the construction industry in the developing world consists of many small-scale stakeholders, who are not able to afford the cost associated with the mechanization and standard planning systems that are required in a PCC technology. In such a scenario, the PCC projects have faced many project-specific issues such as productivity and quality related issues because of less expertise, which in turn escalated the costs and created a negative perception among clients, engineers, architects, and contractors. Research will be a major factor that can help in identifying solutions to such issues. Till date, very few studies were focused on quantifying the factors affecting productivity for such situations in developing countries such as India. An analysis by Li et al. (2014) showed that the developing countries like India are lagging in proper research on management of prefabricated construction. Thus, the primary objective of this study is to quantify the factors leading to poor productivity in PCC projects in developing countries like India. The study also identifies the areas to improve functionality and can form a base for further research in functionality aspects for PCC projects. In the longer run, with widespread usage of PCC, the housing in the developing world will become "more affordable" and the problem of housing shortage could be adequately addressed.

3. PRODUCTIVITY IN PCC PROJECTS

Cost is one of the major variables considered by the construction contractors while selecting the method of construction. Walker et al. (2000) revealed from a consultancy study that construction cost for prefabricated housing is 40% higher than the typical CIC construction. A case study by Kurumoji (2013) reported that the cost of a building constructed by precast concrete methodology can be 25% higher than the traditional CIC methodology, due to site specific productivity issues. As productivity has a direct impact on the construction cost, adaptation of Lean Construction principles may help in identifying and mitigating the factors causing low productivity. Lean Construction Management is a developing construction management paradigm, which focuses on enhancing customer Value, essentially using principles of Continuous Improvement, Collaborative Working and avoiding all types of Wastes. As part of the last-mentioned objective, to improve productivity, the tools such as Work Sampling and Value Stream Mapping can be employed. As part of this, the various activities being carried out can be classified into three: (i) Value Adding (VA), (ii) Non-Value Adding (NVA) and (iii) Non-Value Adding but Required (NVAR). Recent researches by Abdel-Razek et al. (2006) and Ballard et al. (2002) have suggested that the usage of Lean principles significantly helps in improving construction productivity. Nahmens (2009) concluded that application of Lean concepts to a typical production line can reduce the labour, materials, and equipment wastes by about 8, 10, and 12%, respectively.

Work sampling is one such technique that quantifies the amount of time spent by the craftsmen in value adding, non-value adding or non-value-adding-but-necessary works and thereby calculating the 'process wastes' in a particular trade. If the craftsmen are spending more time on the value adding activities, then the productivity of that trade is better as more time is spent on overall valueaddition (Liou and Borcherding, 1986; Thomas et al., 1984). Though work sampling is used by the present-day Lean researchers and practitioners, the roots of work sampling date back to early 20th century when Gilberth and Frederik Taylor had successfully demonstrated the usage of action and time-based study for productivity assessments (Durana et al., 2015).

3.1 Assessment method

Five PCC projects located in three metropolitan cities in India (Mumbai, Chennai and Bengaluru) were chosen for the study. All these projects were residential buildings. The details of these projects are given in Table 1. The structural system of Projects 1, 2, and 3 included wall and solid slab elements. The Projects 4 and 5 consisted of beam, column, and solid slab elements. The actual productivity for each project was evaluated using the Daily Progress Reports (DPRs) obtained from the sites. Further, 'wastes' in each construction processes were quantified using work sampling. Work sampling involves a series of instantaneous observations taken by the observer at random stages during the progress of work and random routes around the site are adopted for these observations. The activities performed in each trade were classified into Value Adding (VA), NonValue Adding (NVA) or Non-Value Adding but Required (NVAR), which are defined as follows.

- VA: 'Value Adding' activities (e.g., direct work items like concreting, erection of precast elements, etc., which create Value for the Client)
- NVAR: 'Non-Value Adding but Required' activities (e.g., supportive work items like erecting and dismantling formwork, transportation of elements, safety precautions, receiving/giving instructions, etc.,)
- NVA: 'Non-Value Adding' activities (e.g., non-productive work items like rework, waiting, unnecessary movements, etc.,)

3.2 Results –Work Sampling (WS)

Four major trades viz. Concreting, Shuttering, Reinforcement and Erection were studied in detail.

The activities such as the workmen moving in the site with tools such as hammer, wheel barrow, vibrator, etc., were recorded under *'moving with tools'* category. The activities such as vertical shifting of precast panels using cranes, horizontal transportation of precast panels, shifting of reinforcement from the laydown area to work table, shifting of precast moulds, etc., were recorded under *'shifting'* category. Workmen taking instructions, participating in training activities, supervision by the site engineers, etc., were considered as *'instruction/supervision'* category. Housekeeping, collection and dumping of wastes were recorded in *'housekeeping'* category. Activities such as oiling/cleaning of mould, vibration of concrete, welding of conduits in

Table 1: Details of construction projects

PCC PROJECT ID	LOCATION OF PRECAST YARD	STRUCTURAL SYSTEM	NUMBER OF TOWERS	NUMBER OF FLOORS PER TOWER	NUMBER OF HOUSING UNITS	COMPLETION LEVEL IN JANUARY 2015 (%)	START MONTH AND YEAR OF THE PROJECT	DURATION OF THE PROJECT (IN MONTHS)
Project 1	On-site	Walls & Slabs	29	12	2784	40	Apr 2013	60
Project 2	On-site	Walls & Slabs	4	12	565	80	Dec 2011	28
Project 3	Off-site	Walls & Slabs	6	23	2112	70	Jan 2013	20
Project 4	On-site	Beams, Columns & Slabs	8	12	768	80	Nov 2012	28
Project 5	Off-site	Beams, Columns & Slabs	8	12	768	10	Sep 2014	30

the panels, hooking/unhooking of crane, curing of concrete and mixing of grout materials were classified as *'others'* category. The time spent on the activities such as *'moving with tools', 'shifting', 'instruction/supervision', 'housekeeping' and 'others'* were recorded as NVAR category. If the workmen were idle without performing any work, waiting for receipt of materials / instruction and making good any damages which have occurred (like repairing the edges of precast panels, rectifying the alignment of reinforcement, etc.,) such activities were recorded under *'idle', 'waiting' and 'rework'* categories respectively.

3.2.1 Overall analysis

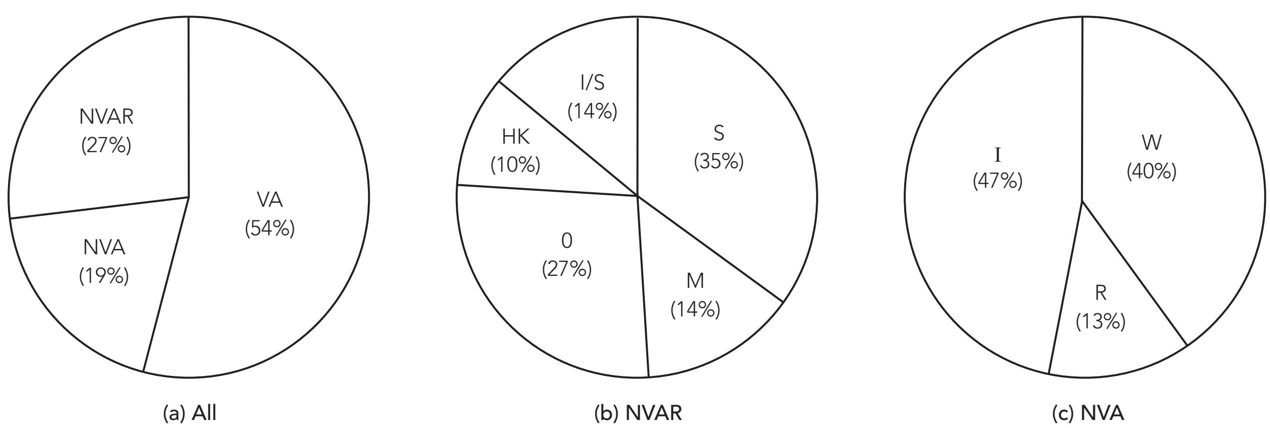
Figure 1 shows the summary of percentages of VA, NVAR, and NVA activities obtained from work sampling data from the five projects. Figure 1(a) shows that about 54% of all the activities were VA activities. This is in agreement with the literature. For example, Kumar et al. (2013), Gouett et al. (2011), Liou and Borcherding (1986) found that the VA activities in CIC projects could range between 30 to 40%, whereas those in PCC projects could be more than 50%. This is because the PCC follows a factorylike production, as compared to CIC. Figure 1(a) also shows that about 27% of all the activities are NVAR activities. More importantly, the NVA activities account to about 19% of all the activities. These NVA activities are 'wastes' that can be eliminated from the processes. Therefore, for achieving more productivity the time spent on NVA and NVAR activities will have to be minimized. Figure 1(b) and 1(c) show the distribution of NVAR and NVA activities from the work sampling data. In the NVAR category, shifting is the highest contributor with 35%. The data indicated that the shifting and/or transportation of precast elements involved long waiting times. However, this waste of time can be minimized with better planning of activities. In the NVA activities, about 47% of time is spent as idle time and 40% on waiting.

3.2.2 Project-wise analysis

Figure 2 shows the work sampling data of the five PCC erection sites under study. The VA activities range around 50%, except in Project 2. In Project 2, severe space constraints for stacking the precast elements led to long waiting time and delays in movements in the supply chain, which in turn led to a reduction in VA activities. The NVAR activities ('NVAR = M+S+HK+I/S+O' as marked in Figure 2) range from 23 % to 38% with the 'shifting (S)' of concrete elements being the major contributor. Project 4 had a well-planned site layout that optimized the movement of workmen and machinery, resulting in about 23% NVAR activities. The NVA activities ('NVA = R+W+I') cover only about 20% of total activities which is very less when compared to cast in-situ construction (CIC) technology. It was observed that the 'waiting (W)' time is high in all the erection sites because of the time spent on waiting for the tower cranes that are required in the erection process. This indicate that optimal planning to ensure the availability of machinery is essential in reducing the wastes in the processes at a PCC site.

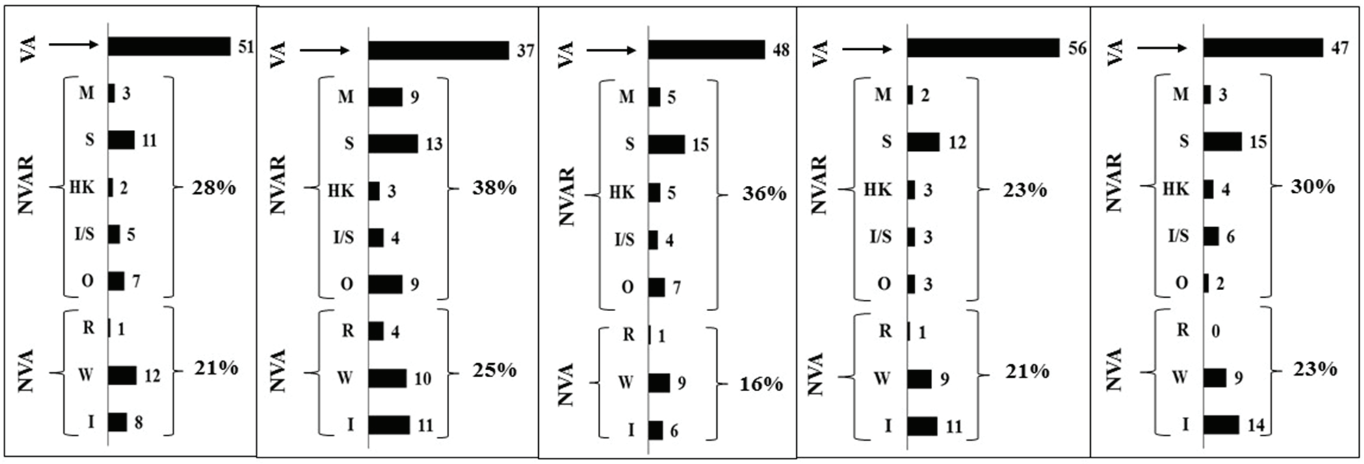
3.2.3 Trade-wise analysis across the projects

Concreting: Distribution of VA, NVA and NVAR activities in the production yards is shown in Figure 3(a). This trade has 52% VA activities. Considerable amount (8%) of 'rework' is due to damage at the corners/edges of precast elements. Mostly, these damages occurred due to improper reinforcement detailing at the edges and poor construction practices. It should be noted that a new industry on 'repair mortar for precast concrete' is upcoming in India. To improve the productivity of 'concreting' trade, 'rework' should be minimized by ensuring proper quality control and better work practices. Also, activities like curing, etc. (classified under 'Others') account for about 10% of time.



Legend: VA – Value Adding activities, M – Movement (With Tools), S – Shifting, HK – Housekeeping, I/S - Instruction/Supervision, O – Others, R –Rework, W- Waiting, I – Idle

Figure 1: Work sampling data of the projects under study: (a) All (b) NVAR (c) NVA



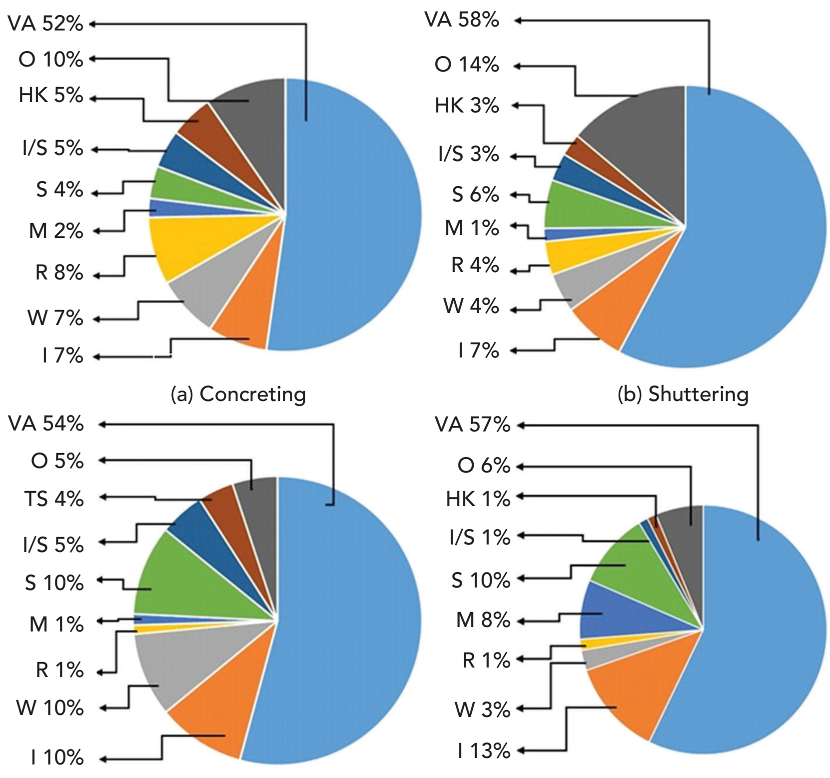
(a) Project 1 (b) Project 2 (c) Project 3 (d) Project 4 (e) Project 5

Legend: VA – Value Adding activities, M – Movement (With Tools), S – Shifting, HK – Housekeeping, I/S – nstruction/Supervision, O – Others, R –Rework, W- Waiting, I – Idle

Figure 2: Comparison of VA, NVA and NVAR from PCC Erection Sites under study

Shuttering: Distribution of VA, NVA and NVAR activities for shuttering trade is shown in Figure 3(b). This trade has 58% of VA activities. "Other" activities like cleaning and oiling of mould account for 14% of time. To increase the productivity of shuttering trade, the methodology of cleaning and oiling of the moulds should be optimized by using appropriate mould releasing agents, which reduces the need and time for cleaning.

Erection: Distribution of VA, NVA and NVAR activities for erection trade is shown in Figure 3(c) - 54% VA, 21% NVA and rest are NVAR. The optimization of the supply chain should be ensured to reduce the 'wastes' due to the waiting for tower cranes, inappropriate driveways and parking spaces for the trailers with precast elements, etc. These apparently seem to be insignificant factors, but this study found that these are



(c) Erection (d) Reinforcement

Legend: VA – Value Adding activities, O – Others, HK – Housekeeping, TS – Temporary Support, I/S – Instruction/Supervision, S – Shifting, M – Movement (With Tools), R – Rework, W- Waiting, I – Idle

Figure 3: Trade-wise work sampling data (a) concreting (b) shuttering (c) erection and (d) reinforcement

significant factors. Providing appropriate paved driveways and parking spaces for trailers can reduce the corner/edge damage of precast elements and reduce waiting time, and thereby increase the productivity in a PCC site in an emerging market.

Reinforcement: Distribution of VA, NVA and NVAR activities for reinforcement trade is shown in Figure 3(d). This trade shows 57% VA activities. Here, the idle time is long (i.e., 13% waste), which should be reduced to enhance the productivity. Also, shifting and movement of reinforcement account for about 18% waste. It was also found that the layout of many PCC sites in India were revised during the project - as adhoc actions. This can lead to unnecessary movement (by large distances within the site) of materials and manpower, which could be avoided by appropriate initial planning of the site layout.

3.2.4 Productivity at production yards and erection sites

Figure 4 shows the bar chart with the contributions of various activities towards the VA, NVAR, and NVA activities – based on the work sampling data. For the discussions in this paper, the production yards are those where the prefabrication process to produce precast panels is carried out and the erection sites are those where the precast panels are assembled and actual buildings are constructed. The white and black bars indicate the percentage of activities at the production yards and erection sites respectively for all the five projects. The VA activities in the production yard are about 9% more than that at the erection sites. Because the production yard system is similar to that of a factory, it has less uncertainties and wastes than the erection sites with greater uncertainties and waiting for material, machinery, and personnel. In the case of NVAR and NVA activities, the delays in 'shifting' and 'waiting' are high in the erection site. These may be attributed to the time taken for the vertical shifting of elements and extra horizontal movement due to the non-optimal location of the tower cranes. Therefore,

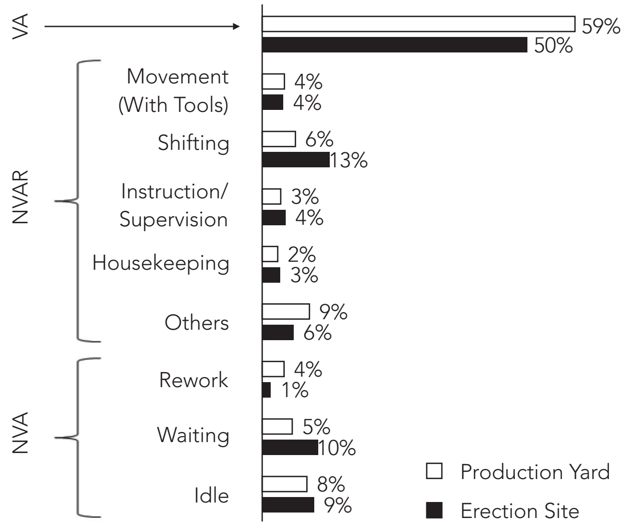


Figure 4: Distribution of VA, NVA and NVAR activities at production yard and erection site

minimal handling/shifting of precast elements must be ensured by proper designing of the site layout (positioning of cranes, driveway layout, locations for stacking, etc.) and planning of site activities (rate of production, scheduling of movement of precast elements, lifting, etc.). Moreover, lack of availability of highly skilled crane operators, was also found as a reason for the low productivity and large waste at erection sites. It should be noted that the other NVAR and NVA activities exhibit similar waste at both production yards and erection sites.

3.2.5 Improvements in productivity

The total productivity of a process is expressed in-terms of output produced per unit of input. The actual productivity for the four major trades viz. concreting, reinforcement, shuttering and erection of precast elements were calculated from the DPRs collected from the project sites and the same is shown in Table 2. As evident by the WS calculations, there are significant

Table 2: Potential improvement in productivity of different trades

TRADE	UNIT OF MEASUREMENT	PRODUCTIVITY NORMS (BASED ON BIS 2010)	PRODUCTIVITY PREVAILING AS PER INDUSTRY STANDARDS (UNIT/MAN-DAY)[a]	ACTUAL PRODUCTIVITY[b] (UNIT/MAN-DAY)	% OF NVA ACTIVITIES IN THE PROCESS	POTENTIAL IMPROVED PRODUCTIVITY (UNIT/MAN-DAY)
Concreting of precast elements	m^3	1.02	1.22	1.10	22	1.57
Shuttering	m^2	0.30[c]	1.70	4.50	15	5.71
Reinforcement	Kg	100	90.50	52.50	17	67.72
Erection of precast elements	Quantity of elements	-	-	0.29	21	0.40

Note: [a]Based on Construction Productivity (2015);
[b]Calculated from the DPRs of the project sites; [c]Includes both fabrication and fixing of shuttering.

amount of "wastes" in each process. If the time consumed on these NVA activities can be converted into value-adding time, then the productivity of each trade can at-least get increased by 15% to 20% as shown in Table 2, thus achieving cost savings.

3.2.6 Reasons for low productivity in PCC sites

Freewheeling/unstructured and on-site interviews were conducted with project managers, planning managers, construction managers, site engineers and heads of departments/divisions handling various sub-activities. In total 52 persons were interviewed and based on these interviews, the factors affecting the productivity were identified. Figure 5 shows the number of times the various factors mentioned by the personnel as leading to low productivity in PCC projects in India. Based upon this, the factors leading to low productivity are grouped into five categories as shown in Figure 6 such as improper planning, rework/repair, improper work methodologies, frequent changes in drawings and other issues.

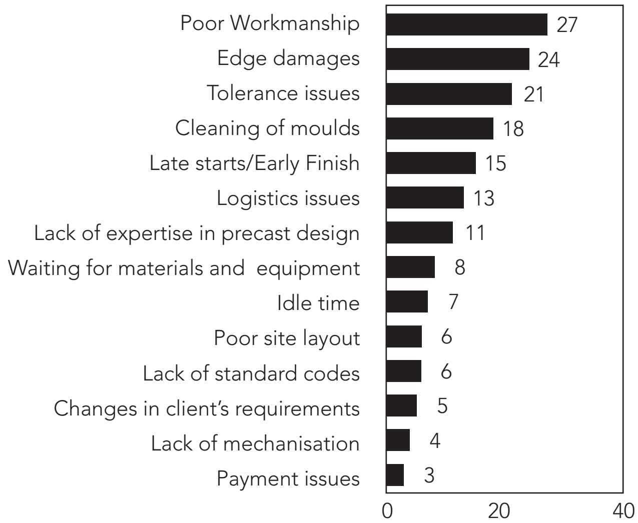


Figure 5: The number of times the issues were mentioned during the free-wheeling interviews, as factors leading to low productivity in PCC projects in India

4. FUNCTIONALITY - LEAKAGES IN PRECAST CONCRETE JOINTS

Joints and connections are critical parts of precast concrete buildings as they are responsible for the structural integrity and water-tightness. Rahim et al. (2012) reported that poor quality joints can adversely affect the durability, fire-resistance, water-tightness, architectural performance, strength/rigidity/ductility for mechanical efficiency, clearances for expansion/contraction, etc. The ingress of water into buildings can lead to mold growth, durability issues, etc., apart from inconvenience to the users and unsightly blemishes which in turn can adversely affect the functionality of a building system. The water leakage issue has been quoted by many researchers (Chiang et al., 2006; Tam et al., 2014) as a key issue impacting PCC. In-spite of the availability of more than 30 Codes of Practice for PCC in India, only a few specifications are available to ensure the water tightness of the joints and connections. In developing countries, the lack of quality control measures to meet the tolerance limits and inadequate workmanship led to poor quality joints (Sherfudeen,

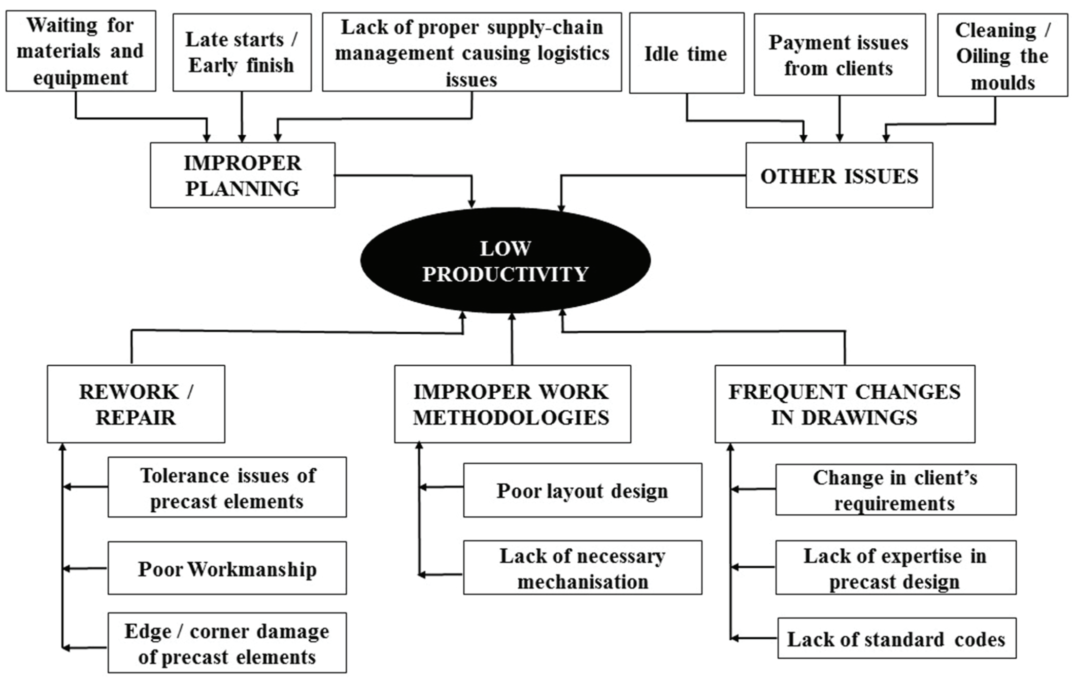


Figure 6: Factors leading to low productivity in PCC projects

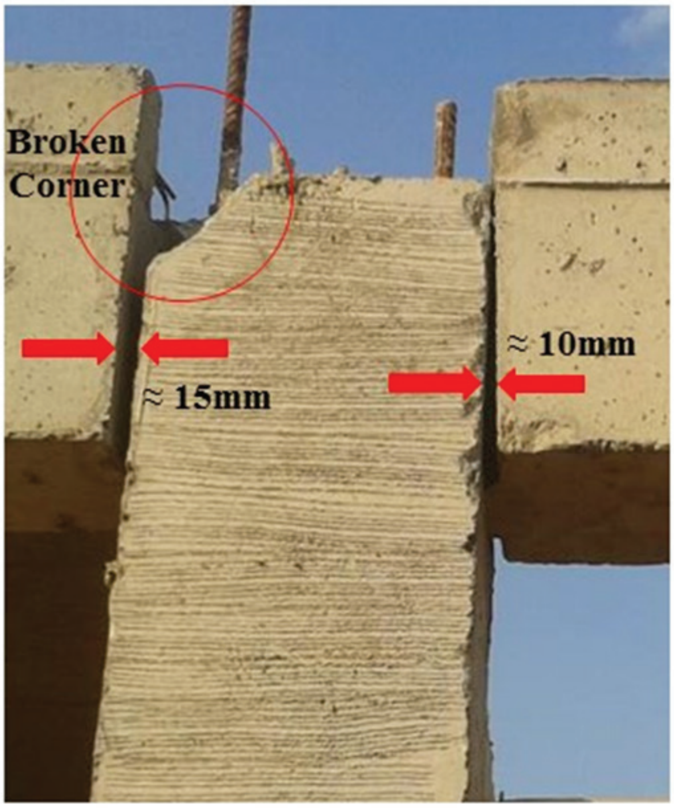


Figure 7: Unwanted gaps at a precast beam-column joint

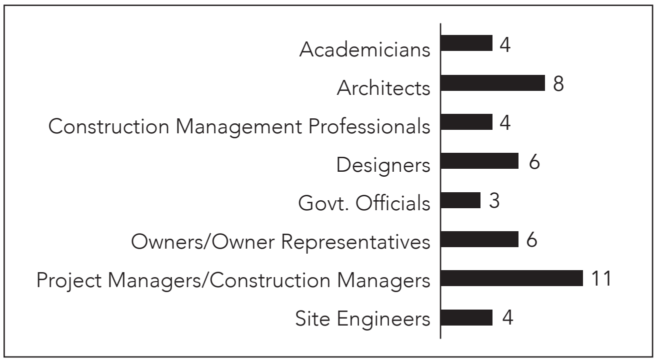
2015). Figure 7 shows the photograph of a typical beam-column joint in a precast building – exhibiting a broken corner on the column, which could lead to additional repair. Figure 7 also shows a gap of about 10 to 15 mm between the end faces of the beams and the column. Such scenarios can lead to additional repair work, leakages, etc. resulting in increased time and cost of construction and poorer functionality.

4.1 Methodology

As there was not much literature found on factors affecting functionality of precast buildings, a questionnaire was framed based on the authors' experience and unstructured interviews conducted with the construction managers of the projects under study. The ten major factors affecting functionality in precast concrete buildings were identified as: (1) Faulty design of joints and connections, (2) Faulty construction methodology, (3) Non-conformance with tolerance limits for precast elements, (4) Frequency of quality checks, (5) Improper grouting of joints, (6) Damage of concrete elements (during moulding/demoulding, handling and transportation), (7) Poor workmanship of joints, (8) Improper type of sealant, (9) Severe exposure conditions (like severe monsoons), and (10) Negligence. More than 150 questionnaires were circulated to various stakeholders like architects, designers, construction management professionals, site engineers, project managers, owners, educationalists, etc. during REDECON 2014 (a five day international conference on PCC at Bengaluru, India). The respondents were asked to rate (among Very Low, Low, Medium, High, Very High) each factor that causes functionality issues (say leakage) in the precast concrete joints and connections. Depending on the responses, a matrix was formed depicting the frequency and severity of each parameter.

Table 3: Number of responses for questionnaire on factors affecting water tightness in precast concrete systems

SL. NO	FACTORS AFFECTING WATER TIGHTNESS	FREQUENCY					SEVERITY				
		VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
1.	Faulty design of joints and connections	1	4	18	15	8	1	7	11	19	8
2.	Faulty construction methodology	4	9	14	13	6	3	15	11	10	7
3.	Non-conformance with Tolerance limits for precast elements	1	8	11	22	4	3	9	13	11	10
4.	Frequency of quality checks	1	11	15	17	2	3	10	18	9	6
5.	Improper grouting of joints	3	5	18	17	3	2	9	20	11	4
6.	Damage of concrete elements (during demoulding, handling and transportation)	2	6	15	22	1	4	5	21	12	4
7.	Poor workmanship of joints	2	4	13	20	7	0	10	13	18	5
8.	Improper type of sealant	4	10	15	7	10	2	18	20	0	6
9	Severe exposure conditions (like severe monsoons)	5	21	7	11	2	11	16	12	5	2
10	Negligence	2	4	17	16	7	4	6	14	22	0



(a) Respondent's Profile

Derived from 46 responses			Severity of ocurances				
			Very Low	Low	Medium	High	Very High
			5	4	3	2	1
Frequency of occurances	Very High	5					
	High	4			4,6	7	3
	Medium	3		2	5,8	1,10	
	Low	2		9			
	Very Low	1					

(b) Frequency and severity matrix

1. Faulty design of joints and connections
2. Faulty con struction methodology
3. Non-conformance with tolerance limits for precast elements
4. Frequency of quality checks
5. Improper grouting of joints
6. Damage of concrete elements
7. Poor workmanship of joints
8. Improper type of sealant
9. Severe exposure conditions (like severe monsoons)
10. Negligence

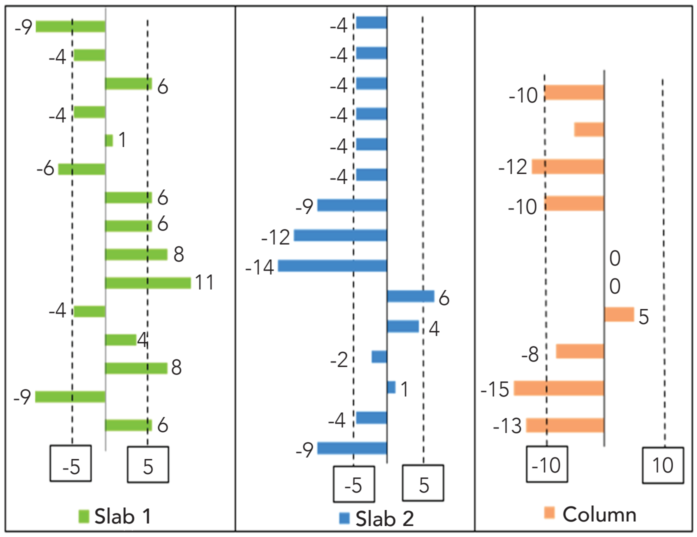
Figure 8: Frequency and severity matrix for parameters affecting water tightness in precast concrete systems

4.2 Frequency-Severity matrix of factors affecting functionality

From the 150 questionnaires circulated, only 46 responses were received. Figure 8 shows the number of responses obtained from various stakeholders. Table 3 shows the number of respondents giving a particular rating (very low to very high) for the frequency and severity of the ten factors under study. Based on this, a frequency-severity matrix was formed, as shown in Figure 8. The numbers (1 to 10) inside the cell refers to the ten factors. The numbers in the top-right region of the frequency-severity matrix, indicate that 'nonconformance with tolerance limits for precast elements' (Factor 3) is having a 'high' frequency of occurrence and has 'very high' severity on affecting water tightness. The respondents also felt that 'poor workmanship of joints' (Factor 7) has high frequency and 'high' severity of occurrence.

4.3 Dimensional tolerances

Tolerance is defined as "the permitted variation from a given dimension or quantity" (ACI, 2000). As found in this study, leakage issues are more likely to occur due to the 'non-conformance with the tolerance limits'. To check if the precast concrete panels produced are conforming to the tolerance limits, the dimensions of 30 precast slabs and 10 precast columns produced in Project 3 were measured. A 5 m long steel tape (Least count = 1 mm) was used to measure the dimensions. As per BIS (2011), the tolerance limits for precast slabs is ± 5 mm and precast columns is ± 10 mm (represented by the dashed vertical lines in Figure 9). The measured dimensions are shown in Figure 9, which indicates that about 40% of the precast concrete elements were failing to conform or comply with the BIS (2011) tolerance limits.



Note: (1) Each horizontal bar represents individual specimens (2) Telerance limits (IS 15916: 2011) for slabs & columns are ± 5 and ± 10 mm, respectively.

Figure 9: Measured dimensional tolerances of precast columns & slabs using steel tape

5. LIMITATIONS OF THE STUDY

There are a few limitations to this study despite the authors' best efforts to make a substantial contribution to the overall body of knowledge through this research. First, generalization of the findings cannot be made based on results just from five construction projects. Second, though about 150 questionnaires were distributed to study the functionality, there were only 46 responses which is generally considered to be on the smaller side for good statistical analysis. However, the findings reported in this manuscript are of importance to enhance the quality and growth of precast concrete construction in developing world.

6. CONCLUSIONS AND SUGGESTIONS

The following conclusions were made from the study:

- About 46% of all the activities are NVA (Non-value adding) and NVAR (Non-value adding but required) activities and this adversely affects the productivity of PCC sites.
- The wastes in the construction processes at erection sites are more than that at the production yards. The wastes at the erection sites can be reduced if the processes can be streamlined with better logistics planning.
- The 'non-conformance with tolerance limits for precast concrete elements' leads to 'high' frequency of occurrence and 'very high' severity of occurrence – with respect to water tightness.
- More than 40% of the precast concrete elements (slabs and columns) checked failed to comply with the tolerance limits possibly leading to water leakage issues.

Based on these conclusions, the authors suggest the following measures to address the productivity and functionality issues in PCC projects in developing countries. They are:

- Ensuring appropriate supply-chain management and good site-layout to reduce waiting, idling and movement and to enhance productivity.
- Increasing awareness about the benefits of PCC may increase the usage, which in-turn make the houses "more affordable", especially with respect to large housing projects.
- Use of better-quality and stiffer formwork can help in meeting the dimensional tolerance limits and ensure the desired functionality.

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