

Northumbria Research Link

Citation: Senarath Jayasinghe, Ruchini and Fernando, Nirodha (2017) Developing labour productivity norms for aluminium system formwork in Sri Lanka. Built Environment Project and Asset Management, 7 (2). pp. 199-211. ISSN 2044-124X

Published by: Emerald

URL: <https://doi.org/10.1108/BEPAM-09-2015-0049> <<https://doi.org/10.1108/BEPAM-09-2015-0049>>

This version was downloaded from Northumbria Research Link:
<http://nrl.northumbria.ac.uk/id/eprint/30785/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



**Northumbria
University**
NEWCASTLE



UniversityLibrary

DEVELOPING LABOUR PRODUCTIVITY NORMS FOR ALUMINIUM SYSTEM

FORMWORK IN SRI LANKA

Ruchini Senarath Jayasinghe

School of Natural and Built Environment,
University of South Australia, Adelaide, Australia,
and

Nirodha Gayani Fernando

Department of Architecture and Built Environment,
Faculty of Engineering and Environment,
Northumbria University, Newcastle upon Tyne, UK

Abstract

Purpose - The purpose of this paper is to establish labour productivity norms (LPNs) on an elemental basis to investigate a measurement for the labour productivity (LP) of aluminium system formwork (ASF) in low-cost housing projects (LHPs) in Sri Lanka.

Design / methodology / approach – Case study approach was selected as the most appropriate for the study and semi-structured interviews, document review and direct observations were used for the data collection. Four case studies were conducted. Eight semi-structured interviews were conducted among four cases. Further, document review was used in three cases, and direct observation was used in one case. The validation of the results was not possible in a real life project due to time limitations

Findings – The findings identified six labour productivity factors (LPFs) affecting the LP of ASF. The need for LPNs for ASF on an elemental basis is identified. Further, LPNs were developed using LPFs.

Research limitations / implications – This research was limited to LHPs for underserved settlements in Colombo, Sri Lanka which use ASF. The LPNs were prepared based on time studies and were restricted to structural elements such as slabs, beams and columns

Originality / value – The LPNs were developed for ASF in LHPs based on the effect of weather, crew, site, management and project factors. Further, the study addresses a gap in the literature regarding the development of LPNs of ASF for LHPs in Sri Lanka. LPNs for ASF have enhanced LP while promoting economic and social stability in the industry.

Keywords: Productivity, Aluminium system formwork (ASF), Labour productivity (LP), Labour productivity factors (LPFs), Labour productivity norms (LPNs), Low-cost housing projects (LHPs)

Paper type Research paper

1.0 Introduction

Brett (1988) defines productivity as, “an index that measures output relative to the input, used to produce them” (p. 51). Productivity fosters satisfied clients, attracts investment and contributes to

economic growth and well-being (Durdyev and Mbachu, 2011). In the construction industry, it enables the efficient use of resources such as material, labour and capital, and labour productivity (LP) stands as a measuring tool since most activities are labour oriented (Mar, 1985; Cheetham and Lewis, 2001). Tools to measure LP are vital for the efficiency of labour-based work in the construction industry (Stiedl et al., 1998). In order to maintain LP, norms are used as suitable standards to facilitate the economic and technological approach and risk management in construction (AbouRizk and Dozzi, 1993). LP is strongly influenced by formwork since it involves a significant portion of the cost of a concrete structure (Tam et al., 2005; Moselhi and Khan, 2010). Aluminium system formwork (ASF) has been identified as the ideal cost-effective tool to enhance productivity for high-rise housing projects (Construction Updates, 2012) and it is a popular formwork system in urban regeneration projects or low-cost housing projects (LHPs) in Colombo, Sri Lanka. Labour productivity norms (LPNs) can thus be used to maintain the LP of ASF and to enhance its effectiveness. There is a deficiency of appropriate norms with which to measure LP for ASF, however, and therefore this research investigates a measure for LP of ASF used in LHPs.

2.0 Construction LPNs

Construction LP is crucial for the effective and efficient utilisation of construction-related resources with minimum waste (Enshassi et al., 2007). According to McDonald Jr and Zack Jr (2004), LP is strongly supported by LPNs. LPNs are defined as the “Number of labour hours required to complete a defined construction activity, under the specific qualifications associated with each individual labour” (Vliet, 2011). It is beneficial in re-measurement, provides easy rectification by employees, maintains the required labour force using the best work practices and enables standardisation and efficient evaluation (Stiedl et al., 1998; Crawford and Vogl, 2006). McDonald and Zack (2004) has developed LPNs for construction formwork using direct observations to facilitate LP.

3.0 Need for LP in LHPs

LHPs are designed for the low and medium income community, using prefabrication or modular components as an efficient mechanism to increase LP (Olotuah, 2002). One such prefabricated material is reusable metal formwork, which is cost effective and productive (Huang et al., 2004; Ministry of Federal Affairs Ethiopia, 2003; Richard, 2005). Effective and advanced formwork systems result in successful LHPs in terms of time, cost and quality (Elbeltagi et al., 2011; Lyngcoln, 1991; Swapnali and Kumathekar, n.d.). When selecting a suitable formwork system, compatibility and maximum reusability are also essential (Smith and Hanna, 1993). Formwork such as timber, steel, aluminium and plywood is used for LHPs in the Sri Lankan construction industry.

3.1 The effect of labour productivity factors (LPFs) on formwork systems

The LP of formwork systems is affected by LPFs such as management, labour, material, technology, and economic and environmental factors (Jarkas, 2010a, b). Figure 1 depicts the relationship between LPFs and formwork. For example, formwork design factors determine the selection and efficiency use of a particular formwork type based on its design and jointing patterns, dimensions and other finishing requirements.

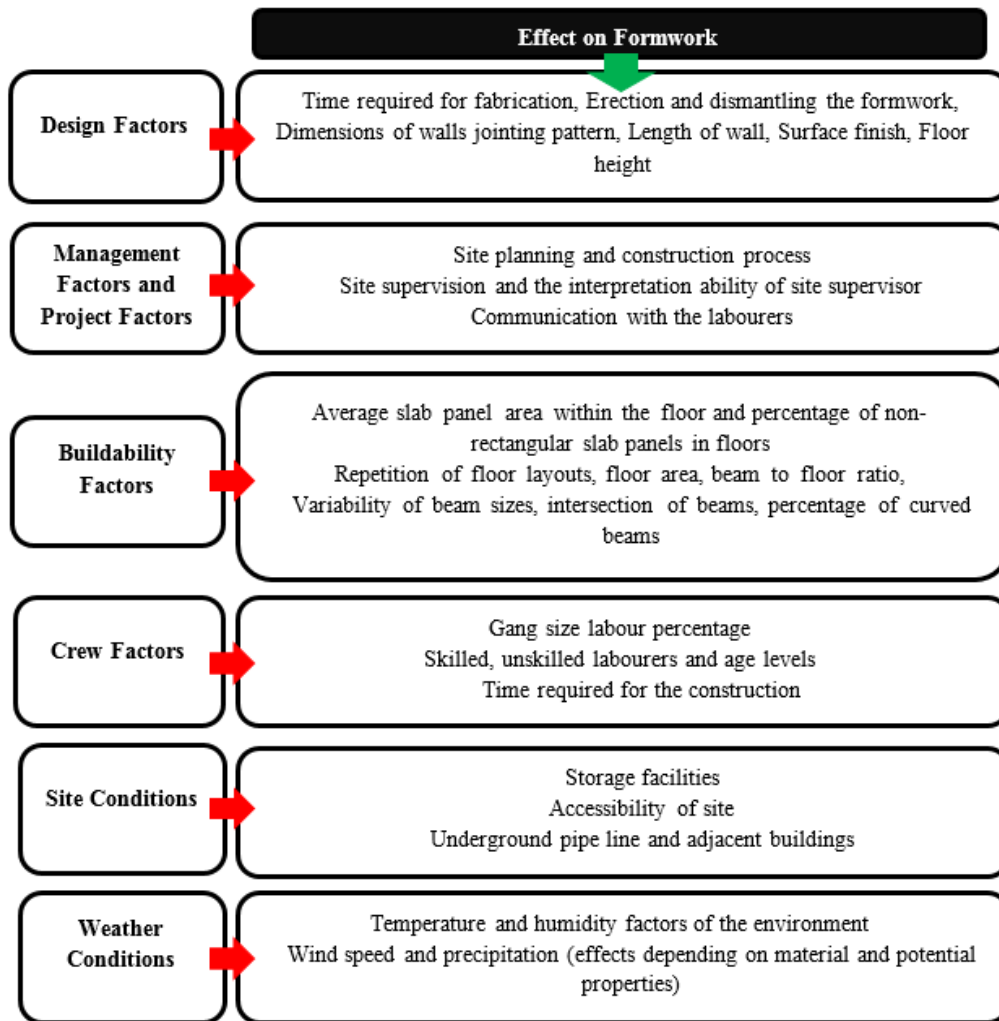


Figure 1. The effect of labour productivity factors on formwork in construction industry

Sources: Tam *et al.* (2005), Smith and Hanna (1993), Jarkas (2010a, b), Moselhi and Khan (2010), Man (nd) and Kazaz and Ulubeyli (2007)

3.2 Significance of ASF in LHP

The selection of an appropriate formwork system is essential to enable speedy construction and to maintain a smooth workflow (Tam *et al.*, 2005). Concrete formwork is labour-intensive, costly and time-consuming, and decreases overall productivity. There should be a mechanism to minimise the cost incurred in formwork by reducing the time frame. Kim *et al.* (2012) devised modular formwork systems, a scientific approach and an optimum solution to improve productivity to overcome cost, time and quality issues. ASF, as a modular formwork system, is an excellent alternative used for

LHPs (Sattigari et al., 2007). Table I provides a comparison between conventional formwork and ASF.

Table I. Comparison between aluminium system formwork with the other conventional formwork system

Requirement	Conventional (timber and plywood)	Aluminium system formwork
Quality	Poor quality- in dismantling	Good quality - in dismantling
Speed	Erection is done at the site. Plastering and finishing activities commence after concreting and de-shuttering	Walls and floors are cast together and enable removal and re-use of formworks on daily cycle basis due to special inbuilt accelerated curing overnight
Finishes	Plastering is required	Rarely required plastering
Maintenance	Plaster of walls /ceiling requires repair and maintenance. Outer and inner walls painting required Leakages occurred in plumbing and sanitation installation.	Concrete repairs for plastering and leakage's are not required due to the walls and ceiling being smooth and high quality
Labour force	Extensive labour requirement	Lesser skill labour requirement, due to standardized and simple installation procedure
Installation and reusability	Maximum 5 or 6 times - shuttering can get damaged when de-shuttering	Lesser material wastage due to standardized and simple installation procedure
Safety	Props are removed when dismantling slab panels	Props are not removed when dismantling slab panels

Sources: Hanna (1999), Huang et al. (2004), and Rahim and Haron (2013)

ASF is economical, and designed for the speed and efficiency of typical high-rise housing construction (Swapnali and Kumathekar, n.d.). It has the high potential to improve LP in LHPs. Gatti et al. (2014) argue that ASF has not achieved successful productivity, however, due to a lack of planning in high-rise construction. There is a need for LPNs in the use of ASF to facilitate LP. ASF is frequently used in LHPs for the relocation of underserved settlements in Colombo, Sri Lanka. This research is especially focussed on enhancing the productivity levels of labourers, and establishing LPNs for ASF in LHPs in Sri Lanka.

4.0 Research methodology

The study investigates the measurement of LP for ASF in LHPs using LPNs through case study approach. It involves expert's interviews, document review and direct observations for data collection. The unit of analysis for these case studies are the LPNs for ASF, within LHPs in Colombo, Sri Lanka, as shown in Figure 2.

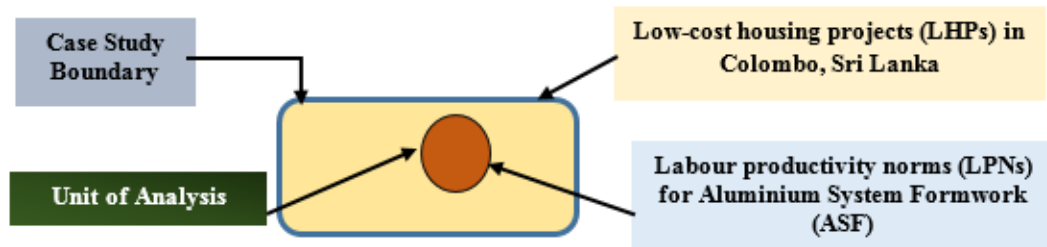


Figure 2. Unit of analysis

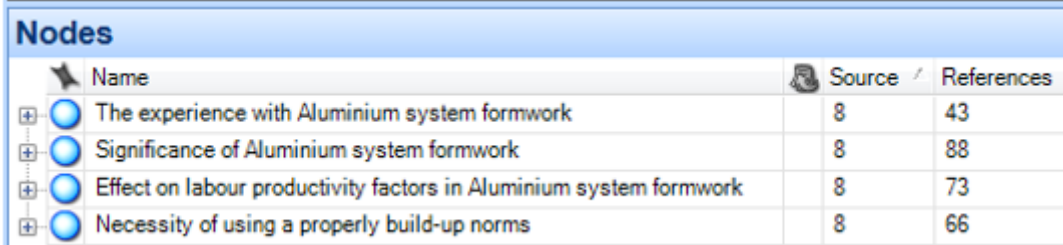
Four LHPs conducted by Urban Development Authority in Sri Lanka were selected as case studies, three cases of which had completed and one was an ongoing project. Table II presents general information about the projects. Initially, semi-structured interviews were conducted to highlight the need for LPNs for ASF. The data collected from the semi-structured interviews were analysed using content analysis. Document review (related to the labour-subcontractor payment certificates), and direct observations were then conducted. The data collected from both methods were analysed using statistical data analysis based on mean values. LPNs were developed based on the results of direct observations, and the results were further examined based on the varying effect of the LPFs in different occasions.

Table II. Summary of the cases

Description	Case 1	Case 2	Case 3	Case 4
Type	Low cost housing projects	Low cost housing projects	Low cost housing projects	Low cost housing projects
Employer	Urban Development Authority	Urban Development Authority	Urban Development Authority	Urban Development Authority
Progress of the Project	Work is on progress	Nearly Completed	Nearly Completed	Nearly Completed
ICTAD Grading	C1	C1	C1	C1
	Building Works	Building Works	Building Works	Building Works
Duration (Months)	24	24	30	24
Payment Method	Design and Build-Lump Sum payment	Design and Build-Lump Sum payment	Design and Build-Lump Sum payment	Design and Build-Lump Sum payment
Contract Price (Rs.)	2.18 Billion	1.36 Billion	2.89 Billion	.915 Million
Floors	12	12	12	12
Work Status	ASF on progress	ASF have already been used	ASF have already been used	ASF have already been used
Interviewees	Site Engineer-1 Site/Project Quantity Surveyor-1	Site Engineer-1 Site/Project Quantity Surveyor-1	Site Engineer-1 Site/Project Quantity Surveyor-1	Site Engineer-1 Site/Project Quantity Surveyor-1
Labels for Interviewees	C1/R1/E	C2/R1/E	C3/R1/E	C4/R1/E
	C1/R2/QS	C2/R2/QS	C3/R2/QS	C4/R2/QS
Expert Interviews	Expert/01	Expert/01	Expert/01	Expert/01
	Expert/02	Expert/02	Expert/02	Expert/02
	Expert/03	Expert/03	Expert/03	Expert/03
Data collection	Direct Observation	Document Review	Document Review	Document Review

5.0 Data analysis – semi-structured interviews

The data collected from the eight semi-structured interviews were analysed using content analysis to investigate the suitability of LPNs for ASF in LHPs, as categorised into several themes. Figure 3 illustrates the coding structure used.



Name	Source	References
The experience with Aluminium system formwork	8	43
Significance of Aluminium system formwork	8	88
Effect on labour productivity factors in Aluminium system formwork	8	73
Necessity of using a properly build-up norms	8	66

Figure 3. Coding structure for investigating the suitability of labour productivity norms for aluminium system formwork in low-cost housing projects

5.1 Significance of ASF

Seven of the eight respondents stated that the overall time consumed for the process of conventional formwork (erection, transportation and dismantle) was the most important issue. C1/R1/E highlighted “Nearly two weeks are taken to complete plywood shuttering for the 4,000 sqft floor. However, ASF approximately takes four days to complete the same area”. In general, ASF is ideal for time saving compared to conventional formwork systems. The quality output of ASF was also highly ranked compared to conventional formwork. The majority of respondents reported that the repetitive use of ASF panels was another advantage due to the typical design of LHPs in the city. The time and quality effectiveness of ASF is a value-added benefit for LHPs.

5.2 LPN for ASF based on LPF

Notably, the positive relationship between LPFs and ASF facilitates implementation of the new system. The majority of interviewees stressed that professionals preferred using ASF to plywood. ASF led to an increase in LP and the need for LPNs due to industry requirements. C2/R2/QS stressed that an elemental basis of LPNs addressed the varying effects of LPFs. According to most of the respondents, LPNs are further affected by the labour force and standardised work practices.

6.0 Data analysis - document review and direct observations

Due to the availability of limited LHPs using ASF, and time constraints, only one case was used for direct observation of ASF construction. A document review was carried out for the three other cases. Four time studies were conducted under the direct observations in Case 1. During these four time studies (four different occasions) effect of LPFs, such as weather conditions, site factors, management and project factors, and crew factors were observed. Since design and buildability factors were similar in the all four time studies in the same case (Case 1), these factors were not considered. All six factors

were identified in the literature review, as crucial LPFs affecting the formwork systems. According to the process shown in Figure 4, the direct observations in Case 1 were entered into the observation sheets while maintaining time allowances for performance rating and performance, fatigue and delay (PFD) allowance. After that, the number of labourers (skilled and unskilled) was multiplied by the time (hours) taken for each task and then divided by the relevant area of the construction work (square metres) to calculate the LPN.

<i>Steps undergone in the site premise</i>	
<i>Step</i>	<i>Description</i>
Observe ongoing work	At the first site visit generally observe the work carried out at the site.
Prepare observation sheet and check list	After observing the methods of construction and the general procedure carrying out by the labourers, observation sheets and the checklist are prepared on the basis of the elements of columns, beams and slabs.
	General procedure for carrying out work
	<u>Pre Concrete stage</u> 1. Preparation - Setting out, transporting the panels 2. Erecting - Preparing tie rods (only for columns), erecting formwork, fastening the jacks and aligning and levelling
	<u>Concreting stage</u> 3. Monitoring the formwork while concreting <u>Post Concrete Stage</u> 4. Process of Dismantling
Divide the work in to work elements	The total work was divided into smaller work components as according to the procedure given below.
Select a particular area for time study	Based on the varying effect of the conditions in LPFs, areas are selected
Measure the time taken to complete each work element	<ul style="list-style-type: none"> • For each divided work elements the time taken to complete a particular task has been measured in minutes and marked in the observation sheet (On an elemental basis such as columns, beams and slabs separately). • The labour force involved in each work element is marked (Skilled & Unskilled). • Note down any specific conditions and remarks • Discuss with site officers or other professionals and confirmed the necessity of LPNs
Quantify and mark the areas where the direct observations are conducted	The areas observed are separately calculated in each time study,

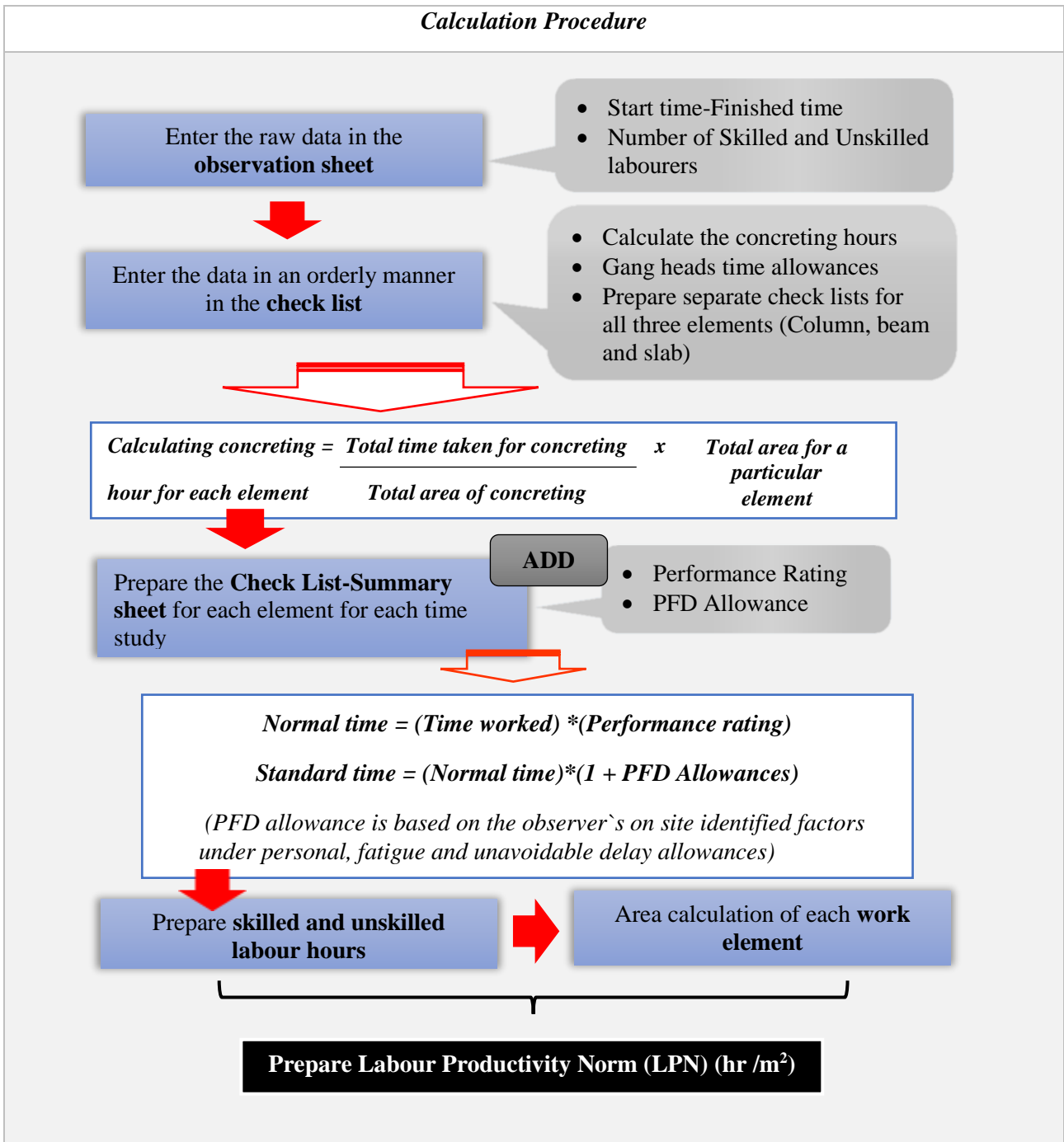


Figure 4. Steps undergone in the site premise and calculation procedure of time studies

The documents reviewed were labour-subcontractor payment certificates for four consecutive months in Cases 2, 3 and 4. According to the documents, LPNs were calculated using skilled and unskilled labour hours, which were computed based on subcontractor payments, and the particular area of the construction work in measurement sheets. The LPNs in both methods were compared, and there were remarkable deviations. The resulting LPNs from the document reviews were considerably less than in the direct observations. This was due to a lack of consideration of LPFs and the special allowances such as performance rating and the PFD allowances in document reviews when calculating LPNs. Only the results of direct observations were selected for the comprehensive analysis, where Table III

presents an in-depth analysis of LPNs based on LPFs and Figure 5 illustrates the results based on structural elements such as columns, beams and slabs.

Table III: Analysis of labour productivity norms based on the varying effect of labour productivity factors

Labour Productivity Factor	Effects on LPN
Weather Condition	<ul style="list-style-type: none"> • In a fair weather condition, the increment in LP is observed. Mix of all weather conditions however, results vast deviations in LP • The impact of the weather conditions in transporting, erecting, dismantling, fastening jacks and aligning the elements, implied that heavy rains had not affected the tasks in a considerable manner • Average LPN had been increased gradually especially in upper floors due to the impact of the wind speed
Crew Factor	<ul style="list-style-type: none"> • Involvement of head of work gang is important for levelling, alignment and setting out activities • A proper labour mix, is required to enhance the labour efficiency. • Experience, teamwork, skills and cooperativeness are essential to follow the work orders, time management
Management and Project Factors	<ul style="list-style-type: none"> • Supervision is required for planning the site schedule • In planning, concurrent operations such as concreting activities and formwork erection need to be considered • Delays in proceeding activities such as reinforcement fixing, cleaning, concreting and scaffolding work has a considerable effect
Site Conditions	<ul style="list-style-type: none"> • Transportation of panels without proper safety procedures under a lack of supervision, delays the scaffolding work • Average facilities of labourers and site security

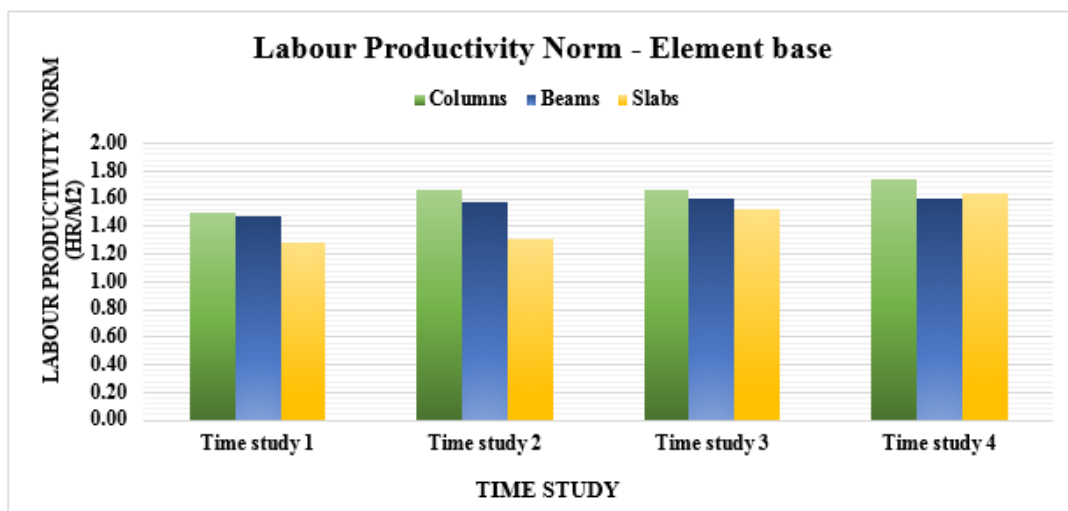


Figure 5. Element base labour productivity norms

According to Figure 5, there is a slight deviation of norms under the varying effects of LPFs. Apart from that initial setting out for the fixing of formwork, the fixing points, supports or props, alignment and involvement of the head of the work gang, handling of panels, re-fixing and the arrangement of the elements were also identified as crucial. LP was also based on the labour mix (skilled and

unskilled), time allocation, the ratio between observed areas of each element and the balance in the productive and non-productive labour hours. All of these are crucial for labour efficiency and vital in the development of LPNs.

7.0 Analysis of LPNs for ASF

The developed LPNs were analysed based on four different occasions, considering the labour mix (skilled and unskilled), the ratio between the areas of each element and varying the effects of LPFs. The changing pattern of LPFs and its impact on LPNs are presented in Table IV.

Table IV. Four different occasions

LABOUR PRODUCTIVITY NORMS (LPNs) – hrs/m²				
	Occasion 1	Occasion 2	Occasion 3	Occasion 4
Average	1.42	1.53	1.60	1.67
Columns	1.50	1.66	1.67	1.74
Beam	1.49	1.56	1.60	1.65
Slab	1.29	1.38	1.53	1.63
Weather condition	Fair	Average	Poor (Combination of all the effects)	Poor (Combination of all the effects)
Crew factors	Proper combination, supervision, and corporation of the labours	Average combination, lesser corporation of the labours as a team	Poor gang head's involvement.	Poor, having lesser experience and lack of team spirit,
Management and project factors	Average planning sequence	Average planning sequence including site supervision	Poor planning sequence	Poor planning sequence
Site conditions	Average site conditions such as site safety and security	Average site conditions including safety and security	Poor site conditions especially the safety factors	Poor site conditions especially the safety factors

According to Table IV, on Occasion 1 the average LPN was 1.42 with a higher level of LP, and the LPNs changed to 1.50, 1.49 and 1.29 for columns, beams and slabs, respectively. On Occasion 2, the average LPN was 1.53, and similar to the Occasion 1 deviations within the elements mainly due to the effect of crew factors. Occasion 3, with average LPN of 1.60 was affected by shortcomings in the weather and management factors. Occasion 4 had a 1.67 average LPN with the worst impact for LP. A progressive increase of LPNs for slabs, columns and beams indicates the need of an element-wise deviation of LPNs. A positive relationship is clearly shown between the severity of LPFs and the average LPN.

8.0 Expert opinions on labour productivity norms

The expert views of LPNs were conducted to get the opinion on the practical and theoretical aspects of the development of LPNs in LHPs. Expert 3 reported that time, cost savings, high quality, planning and labour efficiency facilitated the positive impact of LPNs. Expert 2 highlighted the suitability of combining the different LPFs and characteristics of structural elements. Expert 1 suggested benefits for quantity surveyors in planning, measuring and pricing, and for labour-subcontractors when

planning labour gangs, highlighting the importance of considering several occasions to generate reliability and accuracy. This study has the potential to contribute to the preparation of LPNs under different conditions. It further demonstrates the relationship between LPFs and LPNs of ASF. Ultimately, the critical evaluation of the expert opinions enhanced the quality of the findings in both practical and theoretical aspects. The validation of the LPNs in the real life context was restricted due to the time constraints, lack of availability of ongoing projects using ASF in Colombo area, and ASF is still an emerging technology in Sri Lankan construction industry. Validation of the results, therefore, requires further research for more clarity.

9.0 Discussion

The findings demonstrate the difficulties faced when using conventional formwork systems and the importance of ASF due to its advanced technological impact and time saving. Kim et al. (2012) have also reported that ASF had a good potential for managing cost, time and government requirements. Research findings declare a positive relationship between LP with ASF and LPFs and the impact on LPNs due to varying effects of LPFs. Similarly, Smith and Hanna (1993) found a direct relationship between LPFs and ASF in LPHs. Research findings stress the necessity and importance of LPNs, even though it cannot affect the market rate in the short term. Vliet (2011) highlighted the need for a norm to maintain the required labour force, the best work practices, minimum disturbances and for creating a benchmark to facilitate the standardisation and efficient evaluation of LP. The research was initiated against a background where issues related to ASF of LPHs were crucial, and there was no value adding practice conducted in the industry to enhance the advanced nature of ASF. Results indicate the real benefits of ASF through LPNs. These two different concepts have been connected here, based on the LPFs and other related aspects, in order to provide an effective and efficient atmosphere in the construction industry.

10.0 Limitations

The lack of ongoing construction sites which use ASF was the main limitation to this study. Only one case study was available at the time of data collection. The other cases were studied under the document review. Another considerable limitation was the unavailability of documents to conduct the document review. This research was only considered from the contractor's perspective, and the perspective of the labour-subcontractor and consultant was not taken into consideration. Another limitation is that the observations were conducted daily, and practical difficulties have resulted human errors during the observations. A limited area was covered and only internal erection procedure of the formwork was observed (the external edges were not taken into consideration) under the time constraints and practical difficulties. Similarly, due to the structural arrangement and timing difficulties, some elements were not considered, such as staircases and concrete walls. In most of the

cases, continuous observations were limited as a result of time restrictions, concurrent activities conducted, the involvement of the labourers in those activities and sometimes the uncontrollable behaviour of the labourers.

11.0 Implication of findings to theory and practice

Theoretically, there is a clear-cut relationship between ASF and the LPNs and effect of LPFs on both which has not been previously identified. Economically, LPNs govern LP, mitigate the shortcomings of excess labour use, help to timely completion of the project and ultimately have an impact on future employment market rates. Notably, LPNs motivates construction industry practitioners and facilitate self-commitment and mental health. This affects the well-being of construction professionals and the labourers. The findings have already developed a foundation for influencing the attitudes of clients and construction professionals regarding ASF compared to conventional formwork systems. Psychologically, this creates a friendly environment for the parties, enabling them to work in a peaceful environment with fewer disputes.

12.0 Conclusions

LP plays an essential role in upgrading the concept of “low-cost housing” because it enhances affordability, quality and time saving. An appropriate formwork system, based on LPFs, is one of the best ways to facilitate LHPs. The trend of ASF begun in Sri Lankan LHPs because the systematic and advanced procedures have a positive effect on LPFs, and also fulfil contractual obligations, compared to conventional formwork. The developed theoretical and practical perspectives of LPNs for ASF add extra value to the LP. LPNs have become the governing factor in planning and estimating stages, which ultimately contributes to facilitating standardisation and the efficient evaluation of the project time cost and quality factors. The power of LPNs within the site premises has enhanced the collaboration and teamwork of the industry professionals which is vitally important for the management of physical activities and mental well-being of the professionals. Occasional deviations in LPNs are highlighted due to the varying effect of the LPFs. Not only a single factor but also a combined effect of different factors have contributed the considerable deviations in LPNs. There is a high potential in generalisation of the LPNs for ASF for other different conditions such as different building projects under different contexts in further studies.

13.0 References

- AbouRizk, S.M. and Dozzi, S.P. (1993), “Productivity in construction”, National Research Council, Ontario, available at: www.nrc-cnrc.gc.ca/irc (accessed 29 April 2014).
- Brett, P. (1988), *Formwork and Concrete Practice*, Heinemann Professional Publications, London.

- Cheetham, D.W. and Lewis, J. (2001), "Productivity, buildability and constructability: is work study the missing link?", in Akintoye, A. (Ed.), 17th Annual ARCOM Conference, University of Salford, Association of Researchers in Construction Management, Manchester, pp. 271-280.
- Construction Updates (2012), "Mivan (Aluminium formwork)", available at: <http://constructionduniya.blogspot.com/2012/02/mivan-aluminium-formwork.html> (accessed 11 April 2014).
- Crawford, P. and Vogl, B. (2006), "Measuring productivity in the construction industry", Building Research & Information, Vol. 34 No. 3, pp. 208-219.
- Durdyev, S. and Mbachu, J. (2011), "On-site labour productivity of New Zealand construction industry: key constraint and improvement measures", Australasian Journal of Construction Economics and Building, Vol. 11 No. 3, pp. 18-33.
- Elbeltagi, E., Hosny, O.A., Elhakeem, A., Abd-Elrazek, M.E. and Abdullah, A. (2011), "Selection of slab formwork system using fuzzy logic", Construction Management and Economics, Vol. 29 No. 7, pp. 659-670.
- Enshassi, A., Mohamed, S., Mustafa, Z.A. and Mayer, P.E. (2007), "Factors affecting labour productivity in building projects in the Gaza Strip", Journal of Civil Engineering and Management, Vol. 13 No. 4, pp. 245-254.
- Gatti, U.C., Migliaccio, G.C., Bogus, S.M. and Schnei, S. (2014), "An exploratory study of the relationship between construction workforce physical strain and task level productivity", Construction Management and Economics, Vol. 32 No. 6, pp. 548-564.
- Hanna, A.S. (1999), "Concrete formwork systems", available at: www.scribd.com/doc/30733343/Concrete-Formwork-Systems (accessed 2 April 2014).
- Huang, R. Chen, J.-J. and Sun, K.-S. (2004), "Planning gang formwork operations for building construction using simulations", Automation in Construction, Vol. 13 No. 6, pp. 765-779.
- Jarkas, A.M. (2010a), "The influence of buildability factors on rebar fixing labour productivity of beams", Construction Management and Economics, Vol. 28 No. 5, pp. 527-543.
- Jarkas, A.M. (2010b), "Buildability factors influencing formwork labour productivity of walls", International Journal of Construction Management, Vol. 10 No. 4, pp. 101-117.
- Kazaz, A. and Ulubeyli, S. (2007), "Drivers of productivity among construction workers: a study in a developing country", Building and Environment, Vol. 42 No. 5, pp. 2132-2140.
- Kim, T., Lim, H., Lee, U., Cha, M., Cho, H. and Kang, K. (2012), "Advanced formwork method integrated with a layout planning model for tall building construction", Canadian Journal of Civil Engineering, Vol. 39 No. 11, pp. 1173-1183.
- Lyngcoln, K.J. (1991), "Plywood in concrete formwork", Plywood Association of Australia, Queensland, available at: www.ewp.asn.au/library/downloads/ewpaa_plywood_in_concrete_formwork (accessed 20 April 2014).
- McDonald, D.F. Jr and Zack, J.G. Jr (2004), "Estimating lost labour productivity in construction claims", AACE International Recommended Practice No. 25R-03, Morgantown, WV.

- Man, R.W.W. (n.d.), “Application of formwork for high-rise and complex building structures – the Hong Kong Cases”, Division of Building Science and Technology, City University of Hong Kong, Hong Kong, available at: www6.cityu.edu.hk/construction_archive/major_reference_pdf.aspx?id=132 (accessed 3 March 2014).
- Mar, D. (1985), *Operation and Industrial Management – Designing and Managing for Productivity*, McGraw-Hill Book Company, New York, NY.
- Ministry of Federal Affairs Ethiopia (2003), “Low cost housing Ethiopia: technical manual, Part I”, Ministry of Federal Affairs, Addis Ababa, Ethiopia, available at: www.docdeveloppement-durable.org/.../en-low-cost-housing-ethiopia-technical-man (accessed 11 March 2014).
- Moselhi, O. and Khan, Z. (2010), “Analysis of labour productivity of formwork operations in building construction”, *Construction Innovation*, Vol. 10 No. 3, pp. 286-303.
- Olotuah, A.O. (2002), “Recourse to earth for low-cost housing in Nigeria”, *Building and Environment*, Vol. 37 No. 1, pp. 123-129.
- Rahim, M.S.M. and Haron, N.A. (2013), “Construction cost comparison between conventional and formwork system for condominium project”, *International Journal of Advanced Studies in Computers, Science and Engineering*, Vol. 2 No. 5, pp. 19-25.
- Richard, R.B. (2005), “Looking for an optimal urban residential building system?”, *International Journal of Construction Management*, Vol. 5 No. 2, pp. 93-103.
- Sattigari, N.R., Mahalingam, A. and Thomas, G. (2007), “Automation of scheme preparation and BOQ calculation for L and T-aluform”, *Automation and Robotics in Construction (ISARC 2007) Proceedings of the 24th International Symposium on Construction Automation Group*, IIT, Madras, pp. 274-280.
- Smith, G.R. and Hanna, A.S. (1993), “Factors influencing formwork productivity”, *Canadian Journal of Civil Engineering*, Vol. 20 No. 1, pp. 144-153.
- Stiedl, D., Brudfors, U. and Shone, M. (1998), “Productivity norms for labour-based construction”, *International Labour Organisation, Advisory Support, Information Services, and Training*, Nairobi, available at: www.ilo.org/emppolicy/pubs/WCMS_ASIST_6655/lang-en/index.htm (accessed 12 March 2014).
- Swapnali, M.K. and Kumathekar, M.B. (n.d.), “Comparison of the use of traditional and modern formwork systems”, *Civil Engineering Systems and Sustainable Innovations Proceedings*, Government College of Engineering, Karad, pp. 348-355.
- Tam, C.M., Tong, T.K.L., Lau, T.C.T. and Chan, K.K. (2005), “Selection of vertical formwork system by probabilistic neural networks models”, *Construction Management and Economics*, Vol. 23 No. 3, pp. 245-254.
- Vliet, M.S.J. (2011), “DACE labour productivity norms – the new ‘Gulf Coast’?”, *AACE International Transactions*, Morgantown, WV, available at: www.costandvalue.org/download/?id=2050 (accessed 14 April 2014).