Perceptions Towards Non-Value-Adding Activities During The Construction Process

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Abstract. Non-value-adding activities are pure waste during the construction process. However, most of the construction practitioner does not realise that most of the activities performed during the construction process add no value to their project. A total of 375 numbers of questionnaires distributed to the Developer, Jabatan Kerja Raya, Consultants and Contractors. The study found that awareness by construction participants in Malaysia to take actions against non-value-adding activities during the construction process is relatively low. Through analysed by using the Pareto Chart, it has been found that defects and waiting time are two categories of non-value-adding activities that need to be prioritised by the industry. It is also found that non-value-adding activities most frequently occurred during structural and architectural work. This paper also reviewed on the causes of non-value-adding activities and discussed its effect towards time, cost, quality and productivity of the construction project. This paper is also important to give clearness and broader understandings on this form of waste other than material waste.

Keywords: - defect, non-value-adding, Pareto, waiting time, waste,

1. Introduction

The construction term is used to define the activity of creation physical infrastructure which comprises work such as residential projects, non-residential project, civil engineering and specialist project. The construction industry plays a vital role in economic growth, social and national growth of the country [1]. The constructional field provides the socioeconomic infrastructure for economic growth and defines as an economic engine for developed economies. It produces wealth and quality of life and generate a huge employment opportunities. The construction industry is very complicated industry in nature due to various levels of management, complex design, lot of process and labour intensive.

Nevertheless, despite its importance, the construction industry has many challenges, which requires immediate attention. Common problems in this industry, including low productivity, poor safety, poor documentation, hostile work environments, inefficient costs and low quality of production [2]–[6]. Another major problem involved is the great level of waste, which is undesirable, no added value to the product, and also time and cost consume to remove during the construction process.

Waste in the construction industry has gained attention all over the world. According to Rahman et al., (2012)[4], waste elimination is one of the main objectives in lean construction. Skoyles & Skoyles (1987) [7] argued that waste as one of the weaknesses in the construction industry. Alwi, Hampson, & Mohamed (2002) [8] suggested that a proper understanding is needed about waste. Most of the construction practitioners viewed waste as material waste, or debris. After a systematic review of previous researches on waste, Viana, Formoso, & Kalsaas (2012) [9] divided into three (3) categories, namely, construction material waste (physical waste); non-value-adding activities (process waste); and specific waste (such as accidents and rework). This paper will only focus on the second type of waste which is non-value-adding activities.

This paper will discuss the perception by the construction practitioners towards non-value-adding activities during the construction process. Other than that, it also discuss on the causes of non-value-adding activities

and its effect towards time, cost, quality and productivity of the construction project. By using Pareto Chart, categories of non-value-adding activities that need to be prioritised and need urgency solution from the industry will be shown at the end of the study.

2. Non-value-adding activties (NVAAs) as pure waste in the construction industry

A study by Felipe et al. (2012) [10] found that construction practitioners, including executive level refer waste as scrap at the construction site. However, according to new philosophy developed by Koskela (1992) [11], waste should be referred as any ineffective usage of equipment, materials, labour, or capital during production. Macomber & Howell (2004) [12] emphasized that anything that's not produces value is waste. Furthermore Formoso & Hirota (1999) [13] refer waste to any activity that from the point of view of the client causes direct or indirect costs, but do not add any value to the product.

The term "non-value-adding activities" (NVVAs) is used by Koskela & Sharpe (1994) [14] to explain waste in the lean production philosophy. According to these researchers, only activities that convert materials and/or information towards what is required by the costumer are value added. Han & Lee (2007) [15] claimed that NVAAs consume time and resources, and need to be avoided. Recently, Ralph & Iyagba (2012) [16] used the term non-value-adding activities to differentiate between physical waste and other waste that occurs during the construction process.

Horman & Kenley (2005) [17] in their research found out that on average, 49.6% of time usage in construction are identified as wasteful activities. Unfortunately, most of the construction practitioner does not realise that most of the activities performed during the construction process add no value to their project. Activities such as waiting, rework, unnecessary movement, overproduction, delay, defects, lack of quality, and inventories are wasted because it's given no value-added to the process. These non-value-adding activities occur throughout the entire construction process and contribute through every participant in the project [6]. Josephson & Saukkoriipi (2007) [18] also supported this phenomenon and therefore further suggest that there is probably a lack of knowledge and size of non-value-adding activities in the construction industry.

Non-value-adding activities will give direct effect to the construction process and project but can be avoided by executing work correctly, close monitoring, controlling and planning. Everyone involved in the construction process has potential to contribute to NVAAs, and therefore, affect the process. Therefore, NVAAs can be referred as activities that consume direct and indirect cost, time, resources, labour and space, but gives no value added to anyone involved during the process.

2.1 Categories of non-value-adding activities

Term waste is used to refer non-value adding activities in lean thinking [18]. The "seven wastes", known as "muda", have been proposed by Ohno (1988) [19]. Waste of defects, waste of transportation, waste of processing and waste of inventory refers to the flow of materials, while waste of waiting and waste of motion refers to workers [11]. As highlighted by Motavallian & Settyvari (2013) [20], many researches have added "unused human talent" as the eighth principle of waste [22] - [23].This research categorized non-value-adding activities into eight categories also known as DOWNTIME as shown in table 1.

Table 1: Defination of non-value-adding activities

Type Of Waste	**Define**
Defect	Efforts caused by rework, scrap, and incorrect information.
Overproduction	Production that is more than needed or before it is needed.
Waiting	Wasted time waiting for the next step in a process.
Non-utilised talent	Underutilizing people's talents, skills, and knowledge.
Transportation	Unnecessary movements of products and material.
Inventory	Excess products and materials not being processed..
Motion	Unnecessary movements of people.
Extra processing	More work or higher quality than is required for the customer.

Other than that, there are others NVAAs (also referred as waste) by previous researches. For example, poor quality [6], [23], [24], excessive inspection on site [4], [14], [24], waiting for equipment repair [16], [25], activity start delay [16], [24]–[27], not listening and not speaking [12], poor vehicle and truck movement [28], unnecessary over-order of materials [4], [11], [21], excess materials on site [28], too much material handling [8] [16], long walking distances [24], [26], [29], making do [30], excess information [12] and excessive supervision [24], [27], [31].

However, most of these types of waste above can be included in one of the eight categories of non-value-adding-activities in this research. For example, poor quality can be concluded under the defect category, waiting for equipment under the Waiting time category, and excess material on site, under the inventory category. There are few types of NVAAs that maybe the causes of NVAAs rather than NVAAs itself. For example, unreliable equipment [16], [25] is the cause of defect, waiting time and motion.

2.2 Causes of non-value-adding activities

Koskela & Sharpe (1994) [14] indicated that there are three causes of NVAAs, which are designed in hierarchical organisations, ignorance, and nature of production. These researchers suggested that traditional management, improper process during design, errors, and machine breakdown also contributed to NVAAs. Other than that, Koskela & Leikas (1997) [32] mentioned that NVAAs occurred due to failure to recognize or measure waste, missing information and complicated material flows.

Previous researchers found that lack of skills by subcontractors and traders were among the causes of NVAAs. Furthermore a great deal of NVAAs also contributed by changes in design, poor coordination, weather, poor planning and scheduling, poor supervision, design changes, slow decision making, lack of trades and subcontractor skills, incorrect construction method, delay of materials, communication breakdown, lack of coordination and lack of trust among parties [10], [16], [21].

Researches by Alwi et al.,(2002) [6] and Alarcon (1997) [24] found that poor quality of site documentation, weather, unclear site drawing supplies, poor design, design changes, slow drawing revision and distribution, unclear specifications, management, information and resources are among vital factors of NVAAs. All the causes above can be categorised into 8M's; management, measurement, method, man, mother nature, material, machinery and money. For example, poor coordination, poor planning, poor scheduling, and poor supervision fall under the management categories, whereas lack of trades and subcontractor skills fall under the man categories.

3. Research Methodology

This study aims at to identify the perceptions towards non-value-adding activities by the construction practitioners in the Malaysian construction industry. The respondents involved in this study are client (Jabatan Kerja Raya and private developer), consultants (Architect, Engineer, Quantity Surveyor and Project Manager) and contractors. Only Contractors registered G7with CIDB selected for this study due their expertise and experience in handling mega and complex project and have no limit in tendering project.

Before questionnaire distributed to the respondents, it firstly was validated by the academician, field expert and statistical expert. Pilot test also conducted with 30 numbers of respondents. However, only 23 numbers of questionnaires were returned to the researcher. The internal consistency and inter-item correlation (relationship between items) of the questionnaire was assessed by the Cronbach alpha method. The Cronbach Alpha value calculated for pilot test was 0.912. The questionnaire consists of three (3) sections as below:-

Section (A) is structured to obtain general information and background about the respondents such as type of organization, position and years of experience.

Section (B) is structured to identify the perceptions of construction participants towards non-value adding activities during the construction process.

Section (C) is structured to identify the effect of non-value-adding activities.

4. Result and Discussion

A total numbers of 375 questionnaires distributed randomly through postal mail around Malaysia (125 sets to clients, 125 sets to consultants and 125 sets to the contractors). After a few follow up through email, online application and telephone, a total 106 sets of questionnaire returned to the researcher within 4 weeks, giving a 28% response rate. According to Akintoye (2000) [33], in the construction industry, it is normal to get a response rate between 20%–30% for postal questionnaire. This is supported by Hoe (2005) [34] which indicated that the response rate of 28% is acceptable. Teo & Loosemore (2010) [35] on their study were using survey to collect data, got a 29.1% response rate. They believed that data collected from those respondents were representative of the population as a whole. In addition, Love & Smith (2003) [36] suggested that 30% response rate is considered satisfactory. Therefore, 28% response rate for this study is considered acceptable and represents the population.

The calculated Cronbach alpha value is 0.870 which exceeded the minimum Cronbach alpha value of 0.70 [37]. Findings from the data gathered through the questionnaires are as follows:

4.1 Respondent information

Of 106 questionnaires returned, 34 numbers were from the client, 38 numbers from the consultants and 34 numbers from the contractor. Respondents from Client consists of the private sector and the Government, meanwhile, respondent involved represent consultants are from architect, quantity surveyor and engineer. All contractors responds were registered G7 with CIDB. The each percentage of respondents for these three (3) types of respondents is not too different and almost equal which is between 32%-35%.

As shown in the table 2, 67.9% of the respondents have more than 10 years of experience in the construction industry. It can be seen that those with 26 years and above experience contributes 22.6% of the total

numbers of respondent. According to the data collected, more than half of the respondents mostly participated in government project (53.8%), whereas 34% and 12.3% of the respondents mainly involved in private project and both project ownership respectively.

Table 2: Respondent information

Type of respondent's organization		
	Frequency	Percent
Client	34	32.1
Consultant	38	35.8
Contractor	34	32.1
Total	**106**	**100**
Years of experience		
	Frequency	Percent
0-5 years	18	17
6-10 years	16	15.1
11-15 years	18	17
16-20 years	20	18.9
21-25 years	10	9.4
26 years and above	24	22.6
Total	**106**	**100**
Main project ownership participated		
	Frequency	Percent
Government	57	53.8
Private	36	34
Both	13	12.3
Total	**106**	**100**

4.2 The perceptions of construction participants towards NVAAs

Section B is structured to identify the perception from construction participants towards NVAAs. In this section, respondents were asked four (4) questions. In the first questions, respondents were asked to indicate the frequency of their organization to take actions towards NVAAs during the construction process by using 5-point Likert scale ranging from 1 (never) to 5 (always). This question has been analyzed using the mean value. By referring to Ariola (2006) [38], the mean score from Likert-scale type questions can be interpreted as in Table 3.

From the table 4, it is notable that all seven items mean scores ranged around 2.51- 3.50 which indicate that on average, only sometimes the actions taken by the respondent against NVAAs. This finding supported the problem statement that the awareness among construction participants towards NVAAs is quite low. Investigate the root causes of NVAAs get the lowest mean score (3.06). More than half of the respondents (62%) respondents answer they never (12%), rarely (16%) and sometimes (34%) investigated the root causes of NVAAs in their project.

Table 3: Interpretation of Likert scale for frequency.

Scale	**Interpretation**	**Scale Range**
1	Never	1.00-1.50
2	Rarely	1.51-2.50
3	Sometimes	2.51-3.50
4	Often	3.51-4.50
5	Always	4.51-5.00

Table 4: Actions taken again NVAAs

Actions	**Response %**					**Mean**
	1	**2**	**3**	**4**	**5**	
Identify non-value-adding activities during the construction process.	3%	16%	29%	37%	15%	3.453
Measure the non-value-adding activities during the construction process.	8%	17%	37%	32%	7%	3.132
Identify the causes of non-value-adding activities.	3%	16%	32%	41%	8%	3.359
Investigate the root causes of non-value-adding activities.	12%	16%	34%	29%	8%	3.057
Analyses the effect of non-value-adding activities towards project performance.	3%	14%	31%	40%	8%	3.255
Reduce non-value-adding activities during the construction process.	3%	10%	39%	36%	12%	3.443
Eliminate non-value-adding activities during the construction process.	9%	10%	39%	32%	9%	3.217

Second question in Section B was structured to seek the agreement from the respondents whether NVAAs contribute to poor construction project performance assessed by using 5-point Likert scale representing from 1 (strongly disagree) to 5 (strongly agree) and calculating the mean. The interpretations towards each statement are shown in Table 5 [38].

The finding from the data which tabulate in table 6 shown the mean score for eight (8) categories of NVAAS range between 3.51- 4.50. Therefore, by referring table 5, it can be deemed that an average, the respondents agree that all the categories of NVAAs contribute to poor construction project performance.

Table 5: Interpretation of Likert-scale for agreement.

Scale	Interpretation	Scale range
1	Strongly disagree	1.00-1.50
2	Disagree	1.51-2.50
3	Neither agree/disagree	2.51-3.50
4	Agree	3.51-4.50
5	Strongly agree	4.51-5.00

Table 6: Contribution of NVAAs towards poor project performance

Category	% Response					Mean
	1	2	3	4	5	
Defect	0%	4%	14%	50%	3%	4.104
Overproduction	5%	12%	25%	42%	2%	3.528
Waiting time	0%	4%	12%	44%	4%	4.198
Non-utilised talent	3%	8%	31%	40%	2%	4.019
Transportation	3%	7%	22%	56%	1%	3.698
Inventory	0%	10%	25%	49%	2%	3.708
Motion	1%	9%	31%	40%	2%	3.660
Extra processing	0%	19%	25%	42%	1%	3.528

Third and fourth question in this section structured to identify the categories of NVAAs and type of works where NVAAs frequently occurred. Data were then analysed by using Pareto analysis. Pareto analysis used to find out what problem should be prioritized,and also to identify targets for improvements. Pareto analysis (80/20) using the idea that a large majority of problems (80%) is produced by a few key causes (20%) and also known as the vital few and the trivial many.

Four (4) respondents were not answered these two (2) questions. From table 7 and figure 1, it is notable that defect and waiting time makes up 78% from the total NVAAs occurred during the construction process. Meanwhile, 81% of NVAAs occurred during structural and architectural works (see table 8 and figure 2). Therefore, to improve the construction process, an in-depth study by focusing on root cause analysis will be carried out on these two categories of NVAAs during structure and architecture work.

Table 7: Frequency of NVAAs occurred during the construction process.

Category	Frequency	%	Cumulative %
Defect	48	47%	47%
Waiting time	32	31%	78%
Overproduction	9	9%	87%
Non-utilised talent	4	4%	91%
Extra-processing	3	3%	94%
Transportation	2	2%	96%
Inventory	2	2%	98%
Motion	2	2%	100%
Total	**102**	**100%**	

Table 8: Types of works where NVAAs frequently occurred during the construction process.

Type of work	Frequency	%	Cumulative %
Architectural work	51	50%	50%
Structural work	32	31%	81%
External work	14	14%	95%
Electrical work	5	5%	100%
Mechanical Work	0	0	
Total	**102**	**100%**	

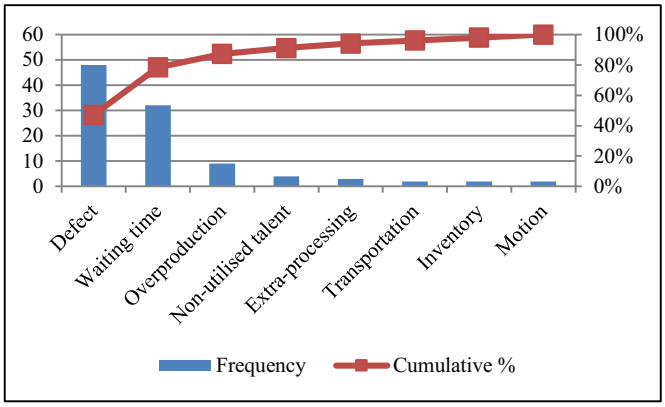

Figure 1: Pareto Analysis on frequency of NVAAs occurred during the construction process.

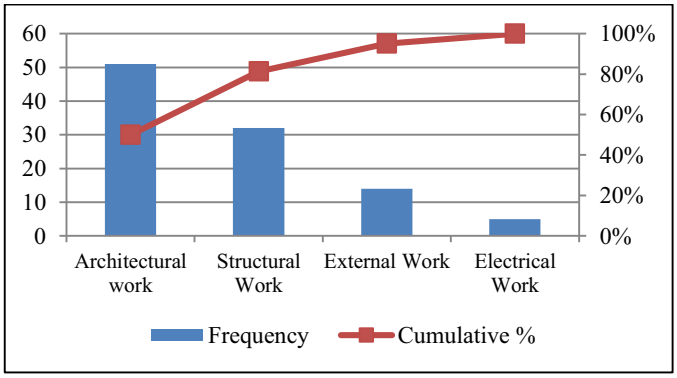

Figure 2: Pareto Analysis of types of works where NVAAs frequently occurred during the construction process.

4.3 Effect of NVAA

Section C on the questionnaire is designed to determine the effect of the non-value-adding activities. Respondents were asked to rate the effect of the NVAAs towards four (4) important parameters in construction projects which are time (T), cost (C), quality (Q) and productivity (P) by using 5 points Likert scale from 1 (no effect) to 5 (major effect). Interpretations for 5 point Likert-scale in effect are as described in Table 9.Data from respondent for this section was calculated by using mean score.

From table 10, it is can be seen that only defect gives major effect towards the quality where it's mean value range 4.51-5.00. The mean score for others parameters for defect are fall under the moderate effect. For waiting time, our finding revealed that it will give major effect towards time. Other three (3) parameters fall under moderate effect where the mean values are 4.14 for cost, 3.54 for quality and 4.05 for productivity. Transportation and overproduction get the lowest mean score are deemed to give neutral effect towards quality.

The average mean score was calculated to identify the overall effect of NVAAs towards the project. Average mean score for seven (7) categories of NVAAs which are defect, overproduction, waiting time, non-utilised talent, transportation, motion and extra-processing towards four (4) parameters are range 3.51 – 4.50, with defect get the highest mean score (4.25) and followed by waiting time (4.06). Meanwhile, the least average mean score is inventory (3.50).

Table 9: Interpretation of Likert-Scale for Effect

Scale	Interpretation	Scale range
1	No effect	1.00-1.50
2	Minor effect	1.51-2.50
3	Neutral effect	2.51-3.50
4	Moderate effect	3.51-4.50
5	Major effect	4.51-5.00

Table 10: Effect of NVAAs towards four (4) parameters

Category	T	C	Q	P	Average mean score
Defect	4.094	4.264	4.585	4.047	4.248
Overproduction	3.472	4.009	3.293	3.538	3.578
Waiting time	4.509	4.146	3.538	4.047	4.059
Non-utilised talent	3.633	3.566	3.660	3.698	3.639
Transportation	3.840	3.934	3.292	3.669	3.684
Inventory	3.519	3.745	3.311	3.443	3.505
Motion	3.705	3.591	3.359	3.679	3.583
Extra-processing	3.585	3.915	3.311	3.528	3.585

5. Conclusion

Non-value-adding activities referred as activities that consume direct and indirect cost, time, resources, labour and space, but give no value added to anyone involved during the process. The eight (8) categories of NVAAs are defect, overproduction, waiting time, non-utlised talent, transportation, inventory, motion and extra processing also known as DOWNTIME. The findings show that awareness among Malaysian construction practitioners against this issue is quite low. The findings discovered that, construction practitioners don't take NVAAs seriously, even though they were agreeing that NVAAs contribute to poor project performance. By using the Pareto analysis and the idea that a large majority of problems (80%) is produced by a few key causes (20%), priorities should be given to solve the problem of defect and waiting time. The study found 78% NVAAs occurred during the construction process are defect and waiting time. Further study should also be focused on structural and architectural works because 81% of NVAAs occurred during these two types of work. Defects and waiting time will give major effect towards the quality and time of the project, respectively. These two types of NVAAs also get highest and second highest averages mean score for overall effect. Therefore, it can be concluded that by eliminating defects and waiting time during structural and architecture work will give a huge impact towards time, cost, quality and productivity of the project.

References

[1] F. Ismail, N. M. Yusuwan, and H. E. A. Baharuddin, "Management factors for successful IBS projects implementation," *Procedia-Social Behav. Sci.*, vol. 68, no. 1877–0428, pp. 99–107, 2012.

[2] L. Koskela, "Lean production in construction," *Elsevier Sci. Publ.*, pp. 47–54, 1993.

[3] A. Forsberg and L. Saukkoriipi, "Measurement of Waste and Productivity in Relation to Lean Thinking," in *Proceedings IGLC-15, July 2007, Michigan, USA*, 2007, vol. 46, no. July, pp. 67–76.

[4] H. A. Rahman, C. Wang, I. Yen, and W. Lim, "Waste Processing Framework For Non-Value-Adding Activities Using Lean Construction," vol. 1, pp. 8–13, 2012.

[5] R. Rivas and A. Serpell, "Evaluation and Improvement of the Procurement Process in Construction Projects," in *Proceeding IGLC-7, University of California, Berkeley, CA, USA*, 1999, pp. 219–230.

[6] S. Alwi, K. Hampson, and S. Mohamed, "Non value adding activities : A comparative study of Indonesian and Australian construction project," *Proc. 10th Int. Gr. Lean Constr. Conf. Gramado, Brazil*, pp. 627–638, 2002.

[7] E. R. Skoyles and J. R. Skoyles, *Waste prevention on site*. BT Batsford Limited., 1987.

[8] A. Sugiharto, K. Hampson, and S. Mohamed, "Factors influencing contractor performance in Indonesia : a study of non value-adding activities," *Proc. Int. Conf. Adv. Des. Constr. Constr. Manag. Maint. Build. Struct.*, vol. 2, pp. 20–34, 2002.

[9] D. D. Viana, C. T. Formoso, and B. T. Kalsaas, "Waste in Construction: A Systematic Literature Review on Empirical Studies," in *Proceedings for the 20th Annual Conference of the International Group for Lean Construction*, 2012.

[10] J. Felipe, P. Achell, and M. B. Bonet, "A preliminary proposal for a waste-based management approach to improve performance in construction," *Proceeding IGLC-21, July 2013, Fortaleza, Brazil*, pp. 115–124, 2012.

[11] L. Koskela, "Application of the new production philosophy to construction," Stanford University, 1992.

[12] H. Macomber and G. Howell, "Two great wastes in organizations : A Typology for Addressing the Concern for the Underutilization of Human Potential," in *proceedings IGLC12, Elsinore, 25-27 July.*, 2004, pp. 1–9.

[13] C. T. Formoso and E. H. Hirota, "Method for waste control in the building industry," in *Proceeding IGLC-7, University of California, Berkeley, CA, USA*, 1999, pp. 325–334.

[14] L. Koskela and R. Sharpe, "Flow process analysis in construction," *Autom. Robot. Constr. 1994, Elsevier Sci. B.V*, pp. 281–288, 1994.

[15] S. Han and S. Lee, "Modeling and representation of non-value adding activities due to errors and changes in design and construction projects," *Proc. 2007 Winter Smulation Conf.*, pp. 2082–2089, 2007.

[16] A. O. Ralph and R. Iyagba, "Factors Affecting Contractor Performance : A Comparative Study of Non Value-Adding Activities in Nigeria and Indonesia," vol. 3, no. 5, pp. 467–474, 2012.

[17] M. J. Horman and R. Kenley, "Quantifying Levels of Wasted Time in Construction with," no. January, pp. 52–61, 2005.

[18] P. Josephson and L. Saukkoriipi, "Waste in construction projects call for a new approach," *chalmers univerity Technol.*, pp. 1–57, 2007.

[19] T. Ohno, *Tovota Production System: Beyond Large-Scale Production*. Productivitiy Pres, Cambridge, MA, 1988.

[20] S. M. Motavallian and H. Settyvari, "Application of Value Stream Mapping in Product Development," Chalmers University of Technology, 2013.

[21] J. Arleroth and H. Kristensson, "Waste in Lean Construction," Chalmers University of Technology, 2011.

[22] J. P. Womack and D. anie. T. Jones, *Lean thinking: banish waste and create wealth in your corporation*. Simon and Schuster., 2010.

[23] B. a. G. Bossink and H. J. H. Brouwers, "Construction Waste: Quantification and Source Evaluation," *J. Constr. Eng. Manag.*, vol. 122, no. 1, pp. 55–60, 1996.

[24] L. F. Alarcon, "Tools for the identification and reduction of waste in construction projects," *Lean Constr.*, pp. 365–377, 1997.

[25] A. Sugiharto, H. Keith, and M. Sherif, "Waste in the Indonesian construction projects," in *Proceedings The 1st International Conference of CIB W107 - Creating a sustainable Construction Industry in Developing Countries , south Africa. Accessed*, 2002, pp. 305–315.

[26] A. Serpell, A. Venturi, and J. Conteras, "characterization of waste in building construction projects," *3rd Work. lean Constr. Albarquerque*, 1995.

[27] S. Senaratne and D. Wijesiri, "Lean Construction as a Strategic Option : Testing its Suitability and Acceptability in Sri Lanka," pp. 34–48, 2008.

[28] F. Emuze, "Non-value adding activities in construction : The case of South African infrastructure sector," *J. Constr.*, vol. 6, no. 1, pp. 5–9, 2013.

[29] R. J. Tersine, "The primary drivers for continuous improvement: the reduction of the triad of waste," *J. Manag. issues*, pp. 15–28, 2004.

[30] L. Koskela, “An exploration towards a production theory and its application to construction,” 2000.

[31] S. G. Modegh, “An evaluation of waste,” in *Proceeding IGLC-21, July 2013*, 1999, pp. 729–738.

[32] L. Koskela and J. Leikas, “Lean manufacturing of construction components,” *Lean Constr.*, pp. 263–272, 1997.

[33] A. Akintoye, “Analysis of factors influencing project cost estimating practice,” *Constr. Manag. Econ.*, vol. 18, no. 1, pp. 77–89, 2000.

[34] L. I. M. K. Hoe, “Causal model for management of subcontractors in waste minimization,” National University of Singapore, 2005.

[35] M. M. M. Teo and M. Loosemore, “A theory of waste behaviour in the construction industry,” no. September 2013, pp. 37–41, 2010.

[36] P. E. Love and J. Smith, “Benchmarking, benchaction, and benchlearning: Rework mitigation in projects,” *J. Manag. Eng.*, vol. 19, no. 4, pp. 147–159, 2003.

[37] C. Nunnally Jum and H. Bernstein Ira, *Psychometric theory*. New York: McGraw-Hill, 1978.

[38] E. A. Ariola, *Principles and Methods of Research*, 1st ed. 2006.