# An Assessment of Lean Construction Tools and Conformance among Pampanga-Based Construction Companies

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**Abstract: -** The construction industry is continuously evolving and improving. Lean Construction is a method used in managing construction projects, which aims to reduce waste while maximizing the value. The implementation of Lean construction is noticeable in several areas around the globe and there is a little information existing about the spread of the implementation among the construction industry in the Philippines. This study aimed to assess the application of lean construction principles and tools in Pampanga-based construction firms. The researchers utilized quantitative, descriptive approach wherein a survey questionnaire was administered among 385 Pampanga-based construction professionals for the awareness and conformance to lean construction, 21 respondents answered a pairwise questionnaire that was used to develop a ISM-based framework where Lean Construction sub-principles were used as variables. The study revealed that most of the tools were used by the respondents but they were not aware that these tools are lean construction tools. The results showed that the conformance to lean principles of the respondents had a 71.80% conformity. Among all the principles of lean, Continuous Improvement principle is the most applied and Culture/People has the least conformance. Moreover, an ISM-based framework was developed to show if one lean sub-principle could help achieve another lean sub-principle.

**Key Words: —** ***Lean Construction, assessment, lean conformance, ISM-based framework, Pampanga-based construction companies.***

## I. INTRODUCTION

From the days that the Egyptian pyramids were built up to the present day, designers and builders have been playing a vital role in providing the needs of the people. The success of the existence of an infrastructure greatly depends on how effective the management of the planning and construction phase is. In the field of Engineering, management involves the organizing and coordinating the work force, machineries, materials and money to have a successful project.

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The construction industry has proven to be one of the sectors that gives great benefit in national economic growth and development (Nwaki & Eze, 2020). Moreover, as the population increases there is a greater need for infrastructure development therefore the construction sector also grows. In addition, as the sector of construction grows, the challenging the managerial work as well as the problems arise from it.

According to Aziz and Hafez (2013), construction wastes, excessive resources consumption, adverse effects on the environment, time and cost overrun are the major issues experienced in construction projects. Likewise, Bajjou et. al (2017) added that the construction industry is characterized by a high level of waste especially in the traditional management system, which leads to the issues stated above. Considering the significance of construction project management in the economic development of the country, there is a greater need to address and explore some new methods and approaches in solving the issues in its sector.

Lean Construction (LC) is one of the proposed solutions to address the problem in the construction management sector. It is considered a new method to manage construction projects, which aimed to reduce waste of material to obtain the maximum value from the process (Li et. al, 2019). Due to the success of the application of lean principles to lean production, the construction industry professionals came up with the idea of applying these principles into its sector.

In several areas around the globe such as the United States, United Kingdom, South America, and Scandinavian countries, the implementation of lean construction is noticeable (Al Balkhy et.al, 2021). The lean movement in the construction industry has taken the interest of researchers and several studies are conducted to assess the potential and factors affecting the implementation of the lean principles in the construction industry of their country.

The Philippines has implemented programs in the development of infrastructure to provide the needs of the stakeholders such as the Build-Build-Build program. The country is managing to cope with the global competition especially in the construction industry. In view of the pursuit of the country to address the problems in the construction sector, it is notable to assess the emergence of this lean construction concept in the country.

Studies have been conducted to assess the level of awareness about Lean Construction however, it is important to evaluate the application of the principles of lean in the construction industry. Herewith, the assessment of the Lean Construction tools and conformance to it is construction project management is necessary in order to know the level of adaptation of lean principles in the Philippines particularly in the Province of Pampanga.

## II. Review Of Related Literature

### *2.1 Lean Construction*

The concept of lean construction is seen as being relatively new in the world of construction companies in comparison to manufacturing. The success of Lean thinking in the manufacturing industry caught the attention of the practitioners in the construction industry. Lean construction concept has been promoted and studied by construction management scholars, practitioners and institutes.

Directly copying the application of this approach in manufacturing is not feasible in the construction industry because of the differences between the two sectors. According to Aziz and Hafez (2013), lean construction pursued the same goals as lean manufacturing.

According to Tommelein (2018), custodian of LCI Glossary stated that Lean construction is about systems thinking, pursuing constant advancement and valuing people, among other things. However, the adoption of lean construction techniques in the construction sector has been slow. Only a very small number of organizations genuinely comprehend what it means to be lean according to several industry experts stated Warcup (2015).

There is a significant number of researches and studies relating to the implementation and awareness of construction companies in the application of lean approach in the construction industry. The related studies implied that LC had positive effects in construction however the main barrier in adapting this new method was the lack of awareness and training about the lean construction method.

### *2.2 Lean Approach in the Philippines*

Several studies uncovered conceptual acceptance and awareness of the lean approach in other countries. In the Philippines, studies of lean management in hospital and manufacturing were present. Alejo (2021) implemented the lean approach in his study to reduce the long waiting times in the Philippine hospitals. It was stated that the concept of lean management was not fully introduced and integrated into hospitals within the country. Moreover, through the implementation of lean methodologies and developed framework in the study of Alejo (2021) it was proven that lean approach significantly contributed toward improving process performance.

In addition, Santos (2019) concluded in this study that the awareness of lean manufacturing was not yet established among the manufacturing firms. The acceptance of the new system was still not acceptable to the employees since the level of awareness was low and even the top management still needed seminars and awareness to fully appreciate lean manufacturing. Moreover, there were limited amount of literature that discussed the implementation and used of lean in the construction industry.

Norona & Mendoza (2020), studied the use of lean approach in adapting modular technology to horizontal construction in the Philippines using lean approach. The survey revealed that among the five delay factors identified, the most frequent and severely affecting factors of delay were material, labor and equipment related delay factors. The highest challenge for adapting the proposed method was shown to be knowledge and transportation related.

The findings of the study of Paguio (2019) revealed that the respondents agreed on lean principles as well as sustainable construction practices in their respective companies here in the Philippines.

Cordova (2018) studied the awareness and effectiveness of lean construction practices in Metro Manila. Results showed that the respondents were much aware of the lean construction elements; however, they needed more training and seminars to be very much aware. Their awareness was just developed because of the length of service in the company and experience on the field of construction. Moreover, they uncovered the effectiveness of lean construction practices in Metro Manila but did not evaluate the current lean practices in Pampanga-based construction firms, which was the focus of this study.

### *2.3 Lean Principles*

According to Al Balkhy and Sweis (2019), Deikman et al. developed a lean construction wheel to assess the lean construction implementation, which shows the same five main principles of the wheel of Tapping et al.

The first principle is the Culture/People, which contains the Training, People Involvement and Organizational. Customer Focus principle comprises two sub-principles: Flexible Resources and Optimize Value. The third principle is the Standardization, which contains the Visual Management, Workplace Organization and Defined Work Processes sub-principles. Continuous Improvement/ Built-in-Quality consist of four sub-principles: Organizational Learning, Metrics, Response to Defects and Error Proofing. Lastly, Eliminate Waste has been divided into four sub-principles; Optimize Production System, Supply Chain Management, Reduce Process Cycle, Time and Optimize Work Content.

## III. OBJECTIVES OF THE STUDY

### *3.1 General Objective*

The study generally aimed to assess the lean construction tools and conformance among Pampanga-based construction companies.

### *3.2 Specific Objectives*

The specific objectives of the study were the following:

1. To determine the current lean construction tools or methods used in Pampanga-based construction companies.
2. To identify the lean awareness and conformance level in the construction industry of Pampanga.
3. To develop an ISM-based framework of recommendation that shows the relationship of the sub-principles of LC formulated by the Pampanga-based construction company's professionals.

## IV. METHODOLOGY

This study adopted quantitative research design and a descriptive approach in collecting quantifiable data from the Pampanga-based construction firms. This study utilized a survey questionnaire that was answered by the respondents to obtain the objectives of the study, which included determining level of conformance to lean principles as well as the current lean construction tools or techniques used in Pampanga-based construction companies.

### *4.1 Research Locale and Respondent Sampling*

#### *4.1.1 for the Lean Tools, Awareness and Conformance:*

This study focused on various construction firms in Pampanga. The respondents were classified based on their position, years of experience and their company category. The survey questionnaires were answered by the respondents who are working as part of the managerial position in the company or firm. They were selected since they are involved in the construction management part of the project. the respondents were selected by the use of a convenience sampling method which represented the characteristics of the population. The sample size calculated for the study is 385 respondents.

*4.1.2 For the Development of ISM-based Model:*

The researchers used another questionnaire in developing the ISM-based Model. The respondents who answered this questionnaire were selected using purposive sampling. The researchers selected the respondents based on their high level of conformance to lean construction principles, which was determined from the first survey questionnaire. The researchers requested the participation of all the respondents who were qualified on the criteria, however, due to the availability and willingness of the respondents, twenty-one (21) pairwise questionnaire was answered.

### *4.2 Research Instrument*

For the validity of the survey questionnaire structure, past studies were adopted and reviewed by the researchers to understand comprehensively more about the topic and sensitivity. Some revisions were made after the expert's validation of the research instruments.

*For the Lean Tools, Awareness and Conformance:*

For this study, a survey questionnaire was used to collect quantitative data that was administered to the selected respondents in Pampanga-based firms in order to determine the use of lean tools or methods, awareness to Lean Construction and conformance to lean principles. The questionnaire adopted both a face-to-face survey and an online survey which consisted of a hardcopy and google forms with a web link. Moreover, the questionnaire consisted of the Demographic profile of the respondent, their Level of awareness towards Lean construction, lean tools, and the level of conformance to lean principles.

The level of awareness of the respondents towards the concept lean construction was scaled with the use of Likert scale.

The Lean tools used for this part were the tools and techniques which are the: Last Planner System, Value Stream Mapping, 5S, Prefabrication, Six Sigma, Poka-yoke (Error Proofing), Just-in-Time, Daily Huddle Meeting and Pull Planning. Respondents in this study were requested to indicate if they have a clear knowledge that the lean construction tool/method is under lean construction and if they are applying or using it in their company.

Furthermore, the questionnaire was be patterned from the thesis entitled, "Lean Construction Conformance among Construction Contractors in Turkey" by Tezel & Nielsen (2013). "Assessing Lean Conformance by First-Grade Contractors in the Jordanian Construction Industry" by Sweis et.al (2016) and "Assessing Lean Conformance by Second-Grade Contractors in the Jordanian Construction Industry" by Albalkhy & Sweis (2019). These studies were adopted and revised by the researchers in order to evaluate the respondents' level of conformance to lean construction practices within their construction firms.

The questionnaire consisted of principles and sub-principles. Generally, some of the sub-principles have more than one question. The Training, Optimize Production System, and Supply Chain Management sub-principles had four corresponding questions. The Reduce Process Cycle Time and Optimize Work Content sub-principles had three corresponding questions. The Flexible resources, Optimized value, and Visual Management sub-principles had two corresponding questions. The rest of the sub-principles had one corresponding sub-principles for each in the questionnaire.

Moreover, to get the statistical data needed by the researchers Likert scale was used. The questionnaire consisted of two statements and the respondents identified their conformance level of the practices to one of these two statements. In principle, the statements on the right represent leaner practices. On the other hand, the statements on the left represent conventional practices.

*For the Development of ISM-based Model:*

A pairwise questionnaire was used to develop the ISM-based model wherein the respondents were asked if one sub-principle helps in achieving the other sub-principles.

### *4.3 Descriptive Analysis*

Percentage or Frequency tally was used to present the frequency of answers regarding the respondent's background. The percentage of how many of the methods or tools were used and known to be under lean construction was presented using this statistical tool.

The level of conformance was calculated as percentage as this study adopted a 5-point Likert's scale, where one indicated that the organizations' practices do not conform with lean construction principles, and five indicated that the organizations' practices fully conform to lean construction principles. The same procedure was applied by Tezel and Neilsen (2013) and Ugurlu et al. (2021).

The research instrument applied the Likert Scale therefore to identify the level of conformance per principle and per sub-principle the mean score was applied. This tool was used by Tezel and Neilsen (2013), Sweis et al. (2016) and Albalkhy & Sweis (2019) in computing for the conformance to lean principles.

The range computed for the level of conformance to lean principles 0.80 where highest weight was 5, lowest score was 1 and the number of weights was 5. Table 1 show the minimum and maximum mean range for every corresponding weight and the interpretation.

Table 1: Interpretation of the Mean Score for Level of Conformance

| Mean Range | Interpretation |
|---|---|
| 4.21 – 5.00 | Most Frequently Being Practiced |
| 3.41 – 4.20 | Frequently Being Practiced |
| 2.61 – 3.40 | Being Practiced |
| 1.81 – 2.60 | Infrequently Being Practiced |
| 1.00 – 1.80 | Not Being Practice |

### *4.4 Interpretive Structural Modelling Methodology*

Interpretive Structural Modelling used a stepwise procedure in developing a framework or model.

Step 1: *Identification of the variables that are relevant to the system.* In this study, the sub-principles of lean construction are considered the variables. These sub-principles are used to

identify the lean conformance of the construction companies being studied.

Step 2: *Establish the relationship among the variables identified in Step 1 based on expert opinion.* A pairwise comparison questionnaire was established to identify the relationship among sub-principles of lean construction. The professionals were chosen from the first survey that was conducted as stated in the respondent's sampling section of the paper. With high level of conformance, the twenty-one respondents provided their expert opinion if one sub-principle can help achieve other sub-principle.

Step 3: *The development of structural self-interaction matrix (SSIM).* The pairwise comparison based on experts' opinion using the V, A, X, O symbols, SSIM was formulated. The following is the description of the V, A X, and O symbol:

- V - sub-principle i will help achieve sub-principal j
- A - sub-principal j will help achieve sub-principle i
- X - sub-principle i and j will help achieve each other.
- O – no relation between sub-principle i and j

Step 4: *Generate a reachability matrix based on the SSIM and check the transitivity of the matrix.* The SSIM is transformed into the initial reachability matrix, a binary matrix, by substituting 1 and 0 for V, A, X, and O, respectively (Yu et al. 2022).

Step 5: *Partition the reachability matrix into different levels.*

Step 6: *Based on the contextual relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.*

Step 7: *The resultant digraph is converted into an ISM, by replacing variable nodes with statements*.

Furthermore, the researchers used the ISM-model generator developed by Ahmad & Qahmash (2021) and established in their study entitled "SmartISM: Implementation and Assessment of Interpretive Structural Modeling". Generator was accessed using a website (http://smartism.sgetm.com/).

## V. RESULTS AND DISCUSSION

### *5.1 Level of Awareness to Lean Construction*

Out of the total 385 respondents, the level of awareness are measured. The highest obtained level of awareness was 38%, stated that they are not aware; while 35% stated that they are slightly aware; 22% of them are aware; and the least percentage of level of awareness to Lean Construction obtained was 5%.

The majority of the respondents' awareness to lean construction per category were not aware and were slightly aware to lean construction concept. Nearly half of the respondents per company positions were not aware and were slightly aware. Moreover, it appeared that the responses from Project managers, General Manager and Operations Manager have a very much awareness to lean construction with each having a percentage of 24%, 13% and 10% respectively. The data suggested that higher managerial positions have a much awareness to the subject matter compared to lower managerial positions.

Based on the years of working experience of the respondents, those who have less than 2 years of experience had the least percentage of not being aware to lean concept while respondent who have more than 10 years of experience had the great number of respondents who were not aware to the concept.

Most of the respondents per company category were not aware to lean construction. Moreover, respondent who were part of a Class AAAA company category has the highest percentage of having a very much awareness to lean concept.

### *5.2 Lean Construction Tools*

Among the Lean Construction tools, the most known and used Lean Construction tool were Prefabrication and Daily Huddle Meeting, both having a percentage of 35% out of the total 385 respondents. Meanwhile, the Lean Construction tool 5s had obtained a percentage of 34% of the respondents that were not aware but still use it. On the other hand, the least known and used Lean Construction tool was Poke-yoke, having 13% of the total 385 respondents. It concluded that the majority of the tools were not well known that they were under Lean Construction but other respondents were already using it.

### *5.3 Conformance to Lean Construction*

#### *5.3.1 Conformance to Lean Construction based on Sub-principle*

The level of conformance of Pampanga-based construction companies to lean construction sub-principles is presented in Table 2. The highest level of conformance with the sub-principles of lean construction was the response to defects with a percentage of 78.70, followed by the metrics and optimize work content having 76.24% conformance. It could be said that there were guidelines on the duties and responsibilities of the people in charge in the project, quality and productivity are frequently being monitored by the people involved.

Based on the results, it was observed the sub-principles under Culture/People yielded the least values in terms of percentage fulfillment. Training and Organizational Commitment were the

sub-principles that were interpreted as being practice and the rest were frequently being practice. In the study of Albalkhy & Sweiss (2019) it was observed that Training scored also the least among the sub-principle with a percentage of 49.17% level of conformance, moreover in this study, Training has 60.16% conformance. This might conclude that companies expected that the employees had enough knowledge and skills to perform their job, allocating time and money for the development of their employees was not on their top priority.

Having a 78.70% to 60.16% conformance to lean construction, with 95% confidence, this might conclude that lean construction concept was already being applied by the Pampanga-based construction companies even though they do not have a high level of awareness to lean construction.

Table.2. Level of conformance to lean construction sub-principles

| PER SUB-PRINCIPLE | Mean | Level of Conformance (%) | Interpretation |
|---|---|---|---|
| CULTURE/PEOPLE | | | |
| Training | 3.01 | 60.16 | Being Practiced |
| People Involvement | 3.49 | 69.74 | Frequently Being Practiced |
| Organizational Commitment | 3.30 | 65.92 | Being Practiced |
| CUSTOMER FOCUS | | | |
| Flexible Resources | 3.78 | 75.69 | Frequently Being Practiced |
| Optimize Value | 3.60 | 72.00 | Frequently Being Practiced |
| STANDARIZATION | | | |
| Workplace Organization | 3.61 | 72.26 | Frequently Being Practiced |
| Visual Management | 3.65 | 72.94 | Frequently Being Practiced |
| Define Work Processes | 3.63 | 72.68 | Frequently Being Practiced |
| CONTINUOUS IMPROVEMENT/ BUILT-IN QUALITY | | | |
| Organizational Learning | 3.61 | 71.10 | Frequently Being Practiced |
| Metrics | 3.82 | 76.42 | Frequently Being Practiced |
| Response to Defects | 3.94 | 78.70 | Frequently Being Practiced |
| Error Proofing | 3.75 | 75.01 | Frequently Being Practiced |
| ELIMINATION OF WASTE | | | |
| Optimize Production System | 3.59 | 71.78 | Frequently Being Practiced |
| Supply Chain Management | 3.52 | 70.43 | Frequently Being Practiced |
| Reduce Process Cycle Time | 3.45 | 69.02 | Frequently Being Practiced |
| Optimize Work Content | 3.82 | 76.42 | Frequently Being Practiced |

*5.3.2 Conformance to Lean Construction based on Principle*

Based on the results presented on Table 3, the highest percentage obtained was 75.56% for Continuous Improvement/Built-In-Quality, which has an interpretation of "frequently being practiced". On the other hand, the least percentage obtained was 65.27% for Culture/People which has an interpretation of "being practiced."

Table.3. Level of conformance to lean construction principles

| PER PRINCIPLE | Mean | % | Interpretation |
|---|---|---|---|
| Culture/ People | 3.26 | 65.27 | Being Practiced |
| Customer Focus | 3.69 | 73.84 | Frequently Being Practiced |
| Standardization | 3.63 | 72.62 | Frequently Being Practiced |
| Continuous Improvement/Built-In Quality | 3.78 | 75.56 | Frequently Being Practiced |
| Elimination of Waste | 3.60 | 71.91 | Frequently Being Practiced |
| **OVERALL LEAN CONFORMANCE** | **3.59** | **71.78** | **Frequently Being Practiced** |

Among the respondents, General Managers had the highest conformance with a mean score of 3.92, it could be said that the principles were frequently being practice. Followed by the Project Managers, Architects and Site Engineers. On the other hand, Project-in-Charge scored the least in the conformance to the principles of lean construction. Moreover, respondents who had the project-in-charge company position got a weighted mean of 2.56 in the Culture/People sub-principle which could conclude that this sub-principle was infrequently being practice. General Managers had high level of conformance knowing that they were part of the top management, moreover lower management had lower conformance since they have do not enough awareness and training regarding lean construction concept.

Respondents with less than two years of working experience had the highest conformance among the others with a weighted mean of 3.76, 75.2% percentage conformance. Meanwhile, respondents with more than 10 years of working experience scored the least with a weighted mean of 3.48. The Continuous Improvement/ Built-In Quality scored 3.93, the highest conformity which was frequently being practice by the respondents with less than two years of working experience. Culture/ People principle had the least conformance of 3.27 by the respondents with 2 to 5 years of working experience.

Class D company category had the highest level of conformance among the company categories with a 73.4% percentage conformity.

### *5.4 Development of the ISM-based framework*

Interpretive Structural Modelling (ISM) is a step-wise procedure used to develop a framework or model. The researchers used the ISM-model generator developed by Ahmad & Qahmash (2021) and established in their study entitled "SmartISM: Implementation and Assessment of Interpretive Structural Modeling".

*5.4.1 Variable in the Interpretive Structural Modelling*

The variable used in this study were the lean construction sub-principles. These were the following:

- Training
- People Involvement
- Organizational Commitment
- Flexible Resources
- Optimize Value
- Workplace Organization
- Visual Management

- Define Work Process
- Organizational Learning
- Metrics
- Response to Defects
- Error Proofing
- Optimize Production System
- Supply Chain Management
- Reduce Process Cycle Time
- Optimize Work Content

*5.4.2 Development of Structural Self-Interaction Matrix (SSIM)*

The criteria in selecting the whether it is V, A, X or O were used in developing the ISM-based framework shown in Table 4. There was a total of 136 pairwise comparison and the results showed that some relationship existed between the sub-principles.

Table.4. Structural Self-Iteration Matrix

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Training | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| People Involvement | | | X | O | O | X | X | V | X | O | X | V | A | X | X | X |
| Organizational Commitment | | | | O | O | X | X | X | X | O | X | X | A | V | X | X |
| Flexible Resources | | | | | X | O | O | A | O | X | O | O | O | X | X | X |
| Optimize Value | | | | | | O | O | X | X | X | O | O | X | O | X | A |
| Workplace Organization | | | | | | | X | X | X | V | X | O | X | X | X | X |
| Visual Management | | | | | | | | X | X | X | O | X | X | O | X | X |
| Define Work Processes | | | | | | | | | X | X | V | X | X | V | X | X |
| Organizational Learning | | | | | | | | | | X | O | O | X | O | A | X |
| Metrics | | | | | | | | | | | O | X | A | O | X | X |
| Response to Deflects | | | | | | | | | | | | X | X | O | O | X |
| Error Proofing | | | | | | | | | | | | | X | X | X | X |
| Optimize Production System | | | | | | | | | | | | | | X | X | X |
| Supply Chain Management | | | | | | | | | | | | | | | X | X |
| Reduce Process Cycle Time | | | | | | | | | | | | | | | | X |
| Optimize Work Content | | | | | | | | | | | | | | | | |

*5.4.3 Reachability Matrix*

The initial reachability matrix, presented in Table 5, was generated by coding the values of V, A, X and O with 1 and 0. It was checked for transitivity and if the matrix was found to be discontented, the SSIM was reviewed and adjusted. After adjusting the transitivity in the matrix, the initial reachability matrix was converted into final reachability matrix.

The final reachability matrix was shown along with the driving power and dependence power. The results shows that all the sub-principles in the matrix were helping each other to achieve one another. The driving power of each sub-principles showed the total number in which it helped to achieve it. The dependence power of each sub-principles showed the total number in which it helped in achieving it.

Table.5. Initial Reachability Matrix

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Driving Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Training | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 15 |
| People Involvement | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 12 |
| Organizational Commitment | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 12 |
| Flexible Resources | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 7 |
| Optimize Value | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 8 |
| Workplace Organization | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 13 |
| Visual Management | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 12 |
| Define Work Processes | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
| Organizational Learning | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 11 |
| Metrics | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 10 |
| Response to Deflects | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 8 |
| Error Proofing | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Optimize Production System | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
| Supply Chain Management | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 9 |
| Reduce Process Cycle Time | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 15 |
| Optimize Work Content | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Dependence Power | 16 | 11 | 15 | 8 | 9 | 12 | 12 | 16 | 12 | 12 | 9 | 12 | 12 | 10 | 14 | 15 | |

Fig.6. Final Reachability Matrix

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Driving Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Training | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 16 |
| People Involvement | 1 | 1 | 1 | 1* | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 16 |
| Organizational Commitment | 1 | 1 | 1 | 1* | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 16 |
| Flexible Resources | 1 | 1* | 1* | 1 | 1 | 1* | 1* | 1* | 1* | 1 | 1* | 1* | 1* | 1 | 1 | 1 | 16 |
| Optimize Value | 1 | 1* | 1* | 1 | 1 | 1* | 1* | 1 | 1 | 1 | 1* | 1* | 1 | 1* | 1 | 1* | 16 |
| Workplace Organization | 1 | 1 | 1 | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 16 |
| Visual Management | 1 | 1 | 1 | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 16 |
| Define Work Processes | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Organizational Learning | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1 | 1* | 1* | 1 | 16 |
| Metrics | 1 | 1* | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1* | 1* | 1 | 1 | 16 |
| Response to Deflects | 1 | 1 | 1 | 1* | 1* | 1 | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1* | 1* | 1 | 16 |
| Error Proofing | 1 | 1* | 1 | 1* | 1* | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Optimize Production System | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Supply Chain Management | 1 | 1 | 1* | 1 | 1* | 1 | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 1 | 16 |
| Reduce Process Cycle Time | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 16 |
| Optimize Work Content | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Dependence Power | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | |

*5.5 Level Partition*

The reachability and antecedent sets were used to after the creation of the final reachability matrix. The reachability set consisted of the sub-principles itself and other sub-principles, while the antecedent set consisted of the sub-principles itself and other sub-principles.

Table.6. Iteration Level

| Elements | Reachability Set R(Mi) | Antecedent Set A (Ni) | Intersection Set R(Mi)∩A(Ni) | Level |
|---|---|---|---|---|
| 1 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 2 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 3 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 4 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 5 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 6 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 7 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 8 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 9 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 10 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 11 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 12 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 13 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 14 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 15 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |
| 16 | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16, | 1 |

The intersection set was obtained after finding both sets, consisting of the same sub-principles found in both sets. The top priority of the ISM was given to the sub-principles which had in common, and the process was repeated until the level of each sub-principle was found.

### *5.6 MICMAC Analysis*

Micmac analysis was used to categorize variables into clusters based on driving power and dependence power. The results of the driving power and dependence variable were translated into four different clusters: autonomous, dependent, linkage, and independent. The results shown in the figure were called "Linkage Variables" due to their strong driving and dependence power. This implied that all sub-principles were helping each other to achieve on another.

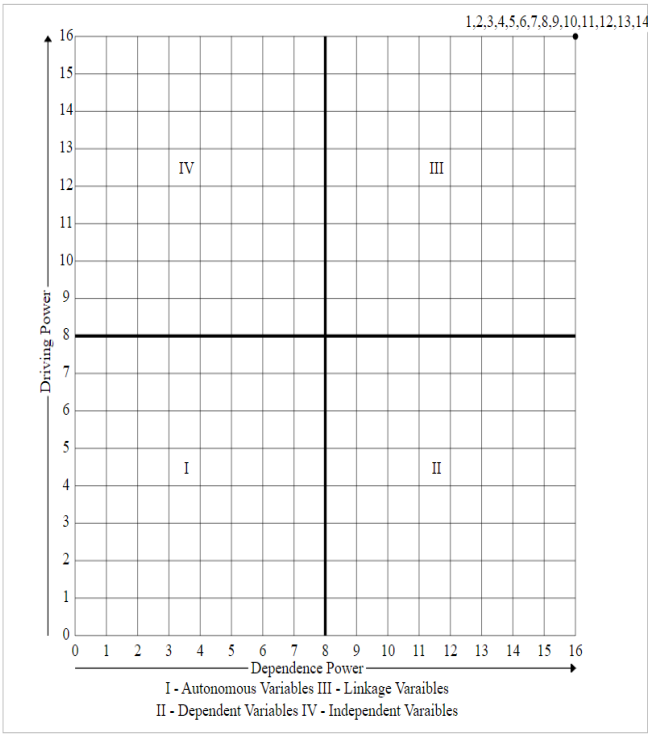


Fig.1. MICMAC Analysis

### *5.7. Resultant Digraph*

A framework was established to identify the levels of each sub-principle, which helped achieve other sub-principles and vice versa as shown in Figure 2. The sub-principles were denoted as nodes and no chronological order was made since all of them influence each other. A total of 136 pairs were made to produce a framework for the lean construction conformance of the sub-principles.

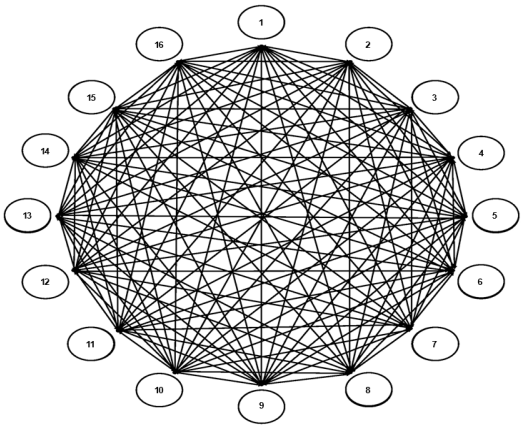

Fig.2. Resultant Digraph

### *5.8 ISM-based Framework*

The resultant digraph is converted into an ISM, by replacing variable nodes with statements. From the experts' opinion who have garnered a high level of conformance and answered the pairwise questionnaire, the results gathered show that each of the sub-principles is important to one another as it helped to achieve a high level of conformance.

The framework presented showed that each sub-principle were interconnected to each other, such as training, people involvement, organizational commitment, flexible resources, optimizing value, and organizing the workplace. The framework helped to visualize the interconnection of each sub-principle, unlike the Lean Construction Conformance based on LC Principles where sub-principles were only connected to the main principles. To fully conform to lean principles, all the sub-principles were needed to be implemented.

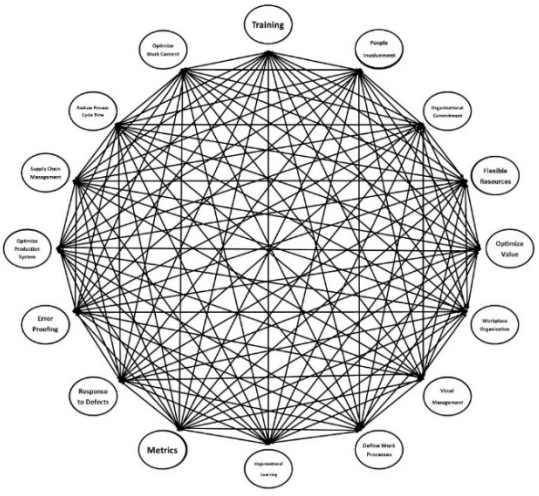


Fig.3. ISM-based Framework

## VI. CONCLUSION

The construction industry in the Philippines is continuously growing and developing especially in terms of the construction management method being use. The assessment of lean construction practices in Pampanga-based construction firm was conducted in order to know if the concept of lean construction was applied and known in the study area. The study will contribute to professionals in the construction management field as well as in the construction industry to explore the current situation of lean construction by assessing the level of implementation or conformance. With the current challenges in the economic situation in the country trying a new concept or other methods in managing construction projects may be helpful. Based on the analyze findings, the drawn conclusion are as follows:

- The majority of the respondents are not aware to lean construction and lean tools but the overall level of conformance to lean principle was interpreted as lean practices are frequently being practice. This implies that the lean concept is already being applied without the awareness that it is a lean concept. Overall, respondents have a low level of awareness but high level of conformance.
- Respondents with more than 10 years of working experience have a lowest lean conformance and awareness compared to respondents with less than 2 years of working experience who scored the highest least conformance among the years of work experience category. This can conclude that respondents with more working experience are still practicing traditional construction methods compared to new concepts such as the lean construction concept. In contrast, respondents who have lesser years of working experience are applying lean construction compared to traditional construction practices.
- Based on the results, 62% of the respondents have no clear knowledge that pull planning is a lean construction tool and 32% of the total respondents are using the said tool while the lean principle that practices pull planning have the second lowest conformance. Since the respondents are not using the said tool, the result of their conformance is relatively low compared to another lean sub-principal conformance.
- The findings of this study showed that majority of the respondents are not using Poka-yoke however, the lean conformance to the Error Proofing sub-principle obtained the third with highest percentage of 75% conformity. It can be concluded that respondents may be using other tools or method to eliminate the defects in their workplace.
- General Managers obtained the highest weighted mean among the other position in the People Involvement sub-principle since they belong to the top management level of their organization.
- Organizational Commitment and Training have the lowest levels of conformity to lean construction. Allocating time and money to enrich the employee's present knowledge is reflected by the commitment of the top management to improve organizational effectiveness. Construction companies may give priority on training in allocating the time and money to enhance the employee's knowledge and skills and to increase their level of conformity.
- From the result of the formulation of the ISM-based framework, it is concluded that from the perception of the respondents, lean construction sub-principles help achieve one another. One may help to increase or decrease the conformance of another.

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