Waste Reduction by Lean Construction - Office Building Case Study

Piotr Nowotarski 1, Jerzy Paslawski 1, Jerzej Skwarek 1

1 Poznan University of Technology, Plac Marii Skłodowskiej-Curie 5, 60-965 Poznań, Poland

Piotr.nowotrski@put.poznan.pl

Abstract. The proper organization and planning of building processes plays an increasingly important role in building projects, and appropriate management is becoming a more frequent problem. Tools of quality management are very often used in other areas of business, such as automotive, aerospace and production, unfortunately, rarely in the field of construction. The main goal of this article is to show that individual quality management tools and Lean Construction tools can be used in construction, and their use brings significant and visible benefits. Authors present their work as an example of implementing these tools in building processes at the construction of Pixel office buildings in Poznań. Authors present the basic concepts related to quality management and the tools used in the field of Lean Construction as well as assumptions of Lean Management. This aims to introduce the reader to the main concept, assumptions and allows to learn the principles of lean management. The reader needs to be aware, that all company employees and suppliers must be involved in introducing Lean Management to the enterprise, starting with the owner and ending with the employee. It is not possible to implement a lean philosophy into a company, without understanding the basics and purpose for which they were introduced. Practical part of the article is devoted to a detailed analysis construction process using the well-known Six Sigma cycle DMAIC - an abbreviation of the words: Define - Measure - Analyze - Improve - Control. The analysis was carried out on the basis of own knowledge and interviews with the construction management and employees of subcontracting companies present at the construction site. Results are presented in the form of conclusions. It can be said that using quality management tools (mainly Lean Management principles) it is possible to visibly improve building processes and it is likely to achieve better financial and time results during execution of works.

1. Introduction
The issue of improving the management of building processes is a complex topic. The necessity of introducing changes has been discussed many times over the years, and the echoes of these discussions are still present in the minds of scientists [1,2,3,4], who have been involved in topics for the last quarter of a century. These calls for changes did not concern only the adoption of new technologies and tools, nor the acquisition of new skills needed to support modern systems [5,6], but paid attention to systemic and organizational problems and the need to promote sustainable development in construction [7]. One of the methods proposed by researchers in improving construction production was and is the application of modern management methods, e.g. Lean Management in construction.
There are many publications showing the effectiveness of individual tools in the field of described methodology [8,9,10]. One of them is DMAIC cycle that enables proper waste identification and elimination.

2. Lean management and DMAIC

Lean Management is strategy to take out conceivable mistakes and wastes while execution of the general processes, which is the reason why it is these days utilized for counteractive action, in case of occurring problems. One of the techniques that can help in effective execution of good practices, which was developed from the quality point of view is DMAIC.

DMAIC is an abbreviation from the words Define-Measure-Analyze-Improve-Control. This strategy depends on procedure improvement as indicated by Deming cycle [11]. This philosophy offers a structure for investigation and analysis of issues; driven by integral assets and procedures [12]. It depends on 5 stages which ought to be executed one by one. Each step can be limited to the questions and doubts that ought to be replied by its users, which are displayed in Figure 1.

![Diagram of DMAIC method]

**Figure 1.** Essential questions for consideration on each step of DMAIC Method [13]

The utilization of DMAIC method is getting more on more popular in processes that are connected not exclusively to the production and manufacturing [14,15,16], yet in addition, IT [17,18,19], healthcare [20,21,22], and numerous others just as to the construction [23,24,25]. This is the main reason authors decided to use it for the purpose of research described in this article.

3. Case study

Authors decided to present the benefits of Lean Construction on the example of Pixel office building construction site. The first of the cluster of five office buildings was commissioned in 2012 and is fully leased by the largest auction company in Poland. Currently, two more were built. The investor also plans to build two more. Buildings have 7 above-ground storeys, one technical storey and they have a shared garage hall occupying 2 underground storeys. In the future, building No. 6 is also planned - a small pavilion in the middle of the Pixel team, with conference functions and facilities for cyclists. Office buildings are built according to today's ecological standards, all of them must obtain a BREEAM certificate at the Very Good level, which shows that today's investors attach great importance to the use of energy and the impact of buildings on the natural environment.

Research were carried out at the buildings no 4 and 5 which construction started in December 2016 and was ended in September 2018. Visualization of the buildings are presented in Fig. 2.
During implementation of Lean Management principles, it was decided to use the DMAIC cycle - it is a series of activities aimed at improving efficiency, reducing waste, optimizing processes. It is usually used in manufacturing companies as an analysis of waste of time or excessive waste. The DMAIC cycle is the main tool of the Six Sigma quality management method, but it is useful when implementing Lean Construction principles at the construction site.

In each phase, many tools are used that are part of quality management. As an example, the Analyze phase can be given: to determine the initial causes of a given problem, the Ishikawa Diagram, also known as the fish bone diagram, is used. Immediately after that, the FMEA analysis was utilized to identify the most problematic factors. In a simple way, when determining the weight of individual problems, the main shortcomings of the whole process were found. At the end, 5WHY’S analysis was performed - it helped to find the primary factors that caused the previously established causes. A cross-section of these three methods in the Analyze phase, introduced a wide range of cause and effect. Each of the processes was broken down into small particles from which a deep analysis could be carried out. After the Analyze phase, the project team moved to the Improve phase. The reasons and effects previously mentioned, as well as measurements from the Measure phase, allowed to start the improvement phase with detailed data and focus on the possibilities to improve.

Lean Management implementation was performed on 3 processes:
- Bricklaying of walls from TeknoAmerBlok blocks
- Delivery and assembly of the building's facade
- Making concrete pots

Out of which bricklaying is presented in detail in this article.

3.1. Process description
When designing the buildings of PIXEL office park, it was decided that all walls in buildings that are not reinforced concrete are to be built out of TeknoAmerBlok blocks. These are concrete blocks, in recent times often used by architects who argue their penchant for them with the beauty of raw concrete. Most of the walls created on the PIXEL site are facing, i.e. the wall is not covered with any cladding. This creates many challenges for the bricklaying company, because the blocks must be clean and
smooth, and the fugue between the individual blocks must be aesthetic, straight and withdrawn from the wall by 1 cm. The example of finished wall is presented in Fig 3.

![Figure 3. Finished wall on the analysed construction site.](image)

The process starts with the delivery of material for construction. Pallets with blocks come to the construction site with a truck and are unloaded using HDS or a tower crane. Then, the pallet is transported to the place of proper installation.

Masonry works start from laying a layer of insulating foil or EPDM foil under the first row of blocks. Then, using the mortar, the first layer of blocks is levelled. Subsequent works consist of building blocks in accordance with the construction art and with several architect's assumptions.

One of the requirements is an aesthetic and even grout in the mortar layer. It has to be withdrawn from the face wall by 1 cm, and high by 1 cm. The masonry team must also remember to make joints clean when making walls, the mortar must not be on the face of the blocks. Depending on the length and height of the wall, horizontal reinforcement is placed every few layers of mortar. They are designed to strengthen walls and improve stability.

In the architectural design, holes were marked which should be made during the erection of walls. Each hole shown on the project is described by a horizontal, vertical, elevation of the bottom of the hole (relative and absolute) and the distance of the vertical axis of the hole from the walls, holes or other characteristic points. The holes made by the masonry team are mainly intended for sanitary or electrical installations. In addition, according to the design, door openings are made. As previously agreed, all openings with dimensions smaller than 200x200mm, or smaller than φ200mm are cut by installation companies after walling a given wall.

Unfortunately, not all openings in the architectural design are compatible with what is actually needed at the construction site. The majority of openings is too large, after passing through the wall of the installation, it turns out in some cases that the installation itself takes up about 10% of the area of the hole. There is a problem related to the re-engagement of the masonry team to brick the majority of the hole, and the use of additional material, sometimes in the finished wall after a design revision, some hole cut or forge - this causes large material losses. It also happens that the hole already made is unnecessary.
The last stage of making the wall is to complement the gap between the last layer of the wall and the ceiling. Filling has the function of dilation between the "working" ceiling and the wall. The gap is filled with mineral wool, which is covered with a fireproof mass of the PROMASTOP-E type from the face of the wall.

![Figure 4. Execution of works at the construction site.](image)

3.2. Define phase
The phase of introducing Lean Management in the analyzed process was started with the project card (Fig. 5), in which the most important information related to the process was recorded. The project card was created at the project meeting convened by the author, aimed at gathering information and setting the DMAIC analysis goals. The main goal was to reduce the amount of waste on the building No. 5 in relation to the waste generated on the building No. 4, where masonry work was started. This has a positive effect on the construction costs of the walls on the construction site by reducing the expenditure incurred to purchase the material. In the project team in addition to the construction engineer, construction site manager, sanitary manager and site manager, the project manager also included a work manager from the subcontractor - a company that executes the walls of TeknoAmerBlok blocks. As the main scope of activity, the phase of preparation for commencement of masonry works combined with the coordination of activities with the installation industry was adopted. The project also includes an action plan to introduce Lean Management principles in the company.

In the Define phase, the project group determined what is the waste in the analyzed process. It was assumed that the waste is called the blocks left after cutting the hole or cutting the block, which are not suitable for reuse. Usually, it is eliminated by defects associated with edge piling and mortar stains on the brick face. The size of the waste can be estimated on the basis of the amount of material ejected by the subcontractor to the container.
The project used the buildings of concrete blocks and bricks to complete TeknoAmerBlok. Hollow blocks come in three thicknesses: 12cm, 19cm and 24cm. The brick is full only in the thickness of 12cm. Depending on the purpose of the wall and its fire resistance, the designer selected the appropriate thicknesses. Table 1 presents a list of the number of square meters of blocks in accordance with the bill made at the offer stage.

Table 1. A slightly more complex table with a narrow caption.

| Material Type   | Use [m²] | Waste [m²] | Waste [%] | Total waste [%] |
|-----------------|----------|------------|-----------|-----------------|
| 12cm brick      | 130      | 7          | 5.38      |                 |
| 12cm airbrick   | 510      | 31         | 6.08      |                 |
| 19cm airbrick   | 1060     | 72         | 6.79      | 6.15            |
| 24cm airbrick   | 645      | 36         | 5.58      |                 |

In the Measure phase, it was decided to take base data created during the execution of walls on the first of the two completed buildings. Figure 6 presents a list of waste and material used. These data were adopted as a reference point for further work related to the reduction of wastage. It is worth noting that the average value of waste for the entire construction process was 6.15%.

3.4. Analyze phase

The Analyse phase was started with the Ishikawa diagram, which was to help determine the causes leading to the creation of excessive waste. Thus, the five most important categories of causes were
found, i.e.: People, Management, Material, Organization, Coordination. Figure 7 presents the results of the analyses carried out:

![Material use and waste](image)

**Figure 6.** Material use and waste.

Then, to determine which of the reasons for waste generation are the most important FMEA analysis, which used to determine three specific factors taking into account the impact on cost / waste, the ability to detect and the frequency of their occurrence. After conducting the FMEA analysis, it was found that the most important reasons are:

- Lack of coordination between industries
- No reconciliation at the beginning of work
- Lack of coordination by designers

The WHY’S method 5 was used to further analyze the causes. It allowed to find the root causes of the most important problems identified in the FMEA analysis which made it possible to perform some actions influencing rate of waste in the improve phase.
After conducting brainstorming in the above tables during the 5Why's method, the project group distinguished three most important primary causes:

a) Lack of employees  
b) Lack of joint meetings  
c) Lack of integration

3.5. Improve phase
Based on the results from the previous phase, the project group proposed to the Project Manager the following changes in the functioning of the construction process:

- Employment or transfer from another construction of at least one person from the general supervision of the contractor.
- A decision was made to accept one more person from the engineering team. The given person will support the team in terms of inter-branch coordination, checking the correctness of the works carried out and quality control during the works performed.
- Introduction to the schedule of weekly meetings with the bricklaying company together with the installation subcontractor.

Meetings, held once a week, will allow construction supervision and subcontractors to better communicate, establish a daily work schedule and better synchronization of fronts of both companies. In addition, a note from the meeting will contain a table in which will be marked places ready to brick up. Additionally, in order to minimize problems related to communication, it was decided to introduce the principle of informing each other also via e-mail. The messages will also be sent to the construction manager, which will help solve possible problems in a wider circle. The team leader, i.e., the Project Manager, also decided to organize the integration trip of supervisory staff to improve communication in the team.

The above recommendations were in the course of construction implemented after the experiments during the works on the building No. 4. During the works on the building No. 5, a new construction engineer was introduced, weekly meetings were initiated and attention was paid to providing information by e-mail. The integration trip is planned after completion of the investment.

![Material use and waste after improvements](image)

**Figure 8.** Material use and waste after improvements.
3.6. Control phase
Implementation of improvements to the process aimed at reducing waste ran from March to July 2017. As part of the inspection, during the works on the building No. 5, the measurements of the walls were made together with the calculation of the waste generated. If too much non-reusable material was found, the supervision was to conduct a special coordination meeting. The solutions introduced, proposed in the IMPROVE phase, did not force supervision to organize such a meeting. In Figure 8, it can be seen that the resulting waste decreased by almost half.

4. Conclusions
The process of introducing Lean Management principles in the wall masonry process carried out on the construction site can be considered successful. Due to a thorough analysis of the causes and problems by the called project group, it was possible to indicate the original causes of the resulting too large waste during the erection of the walls of TeknoAmerBlok blocks. The conclusions are as follows:

- After the implementation of improvements, the amount of waste decreased by 6.15% to 3.39%, i.e. the waste is formed by half less.
- An additional engineer was hired, who by his work contributed to the improvement of the analyzed process as well as to many others - for example during finishing works.
- Improved communication in the team, as well as with subcontractors, improved the efficiency of the work of engineering staff as well as subordinate companies.

The purpose of the following analysis was achieved thanks to the implementation of the Lean methodology using the DMAIC cycle. The solutions introduced to the bricklaying process were also applied in other processes carried out on the PIXEL site in Poznań. According to the author, the tools used should be implemented on the site earlier, already at the stage of "driving the first shovel".

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