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Streamlining Construction Operations: A Holistic Approach with A3 Methodology and Lean Principles

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Abstract: With the growing trend of urbanisation and the growing number of people migrating to cities, the demand for the development and construction of new buildings and infrastructure has risen, meaning that the construction industry must adapt to these trends. Growing demands with shorter deadlines for an industry already known for its high costs and late delivery means that productivity must be increased without increasing costs. The solution for this might lie in the application of the Lean philosophy to the construction industry. This paper analyses the application of the Lean philosophy in order to increase the productivity of construction work for an airport project. This paper highlights the potential for enhancing productivity in construction workplaces by concurrently fostering continuous improvement and sustainability through the implementation of the A3 methodology and Lean principles, resulting in waste reduction and increased value.

Keywords: lean management; A3 methodology; optimisation; construction site; continuous improvement

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1. Introduction

Lean represents a philosophy created by the Toyota Production System. Construction projects present a breeding ground for innovation, development, and improvement while also producing a lot of waste within their processes, resulting in missed deadlines and, in turn, high costs [1,2]. One of the challenges that the construction industry faces when it comes to waste is not only that it exists in construction processes but that it is very much accentuated in the supply chain [3]. Inefficient and costly construction work represents a complete contradiction to the Lean philosophy, making the construction industry an ideal candidate for the application of Lean to reduce and eliminate waste. While it might seem that Lean and construction share no common ground, there are similarities between the two. Perhaps the most important one is that both aim to create more value defined by the customer.

Nowadays, there are numerous challenges to adapting Lean principles, particularly in process industries, and even more so in the construction industry. As described in the works of Moradi and Soormunen [4], the barriers to adapting Lean to these industries are quite similar and include resistance to change and lack of support from top management. However, a significant difference is that the primary issue in adapting Lean to construction is the lack of awareness and understanding of how Lean can benefit construction projects. This highlights that even after 30 years of applying Lean principles in the construction industry, this fundamental problem persists.

The construction industry can be considered a non-repetitive industry where daily activities vary significantly, processes and work areas change frequently, and logistics are difficult to predict and depend on many variables, unlike in other industries. Researchers and professionals are developing new tools and techniques to overcome these barriers and facilitate the adaptation of Lean principles to construction projects. As described in the works of Sanchez and Revuelta et al., researchers are using various visual and educational games to make Lean principles more accessible and comprehensible for practitioners who will implement them in real-world scenarios [5].

One of the most critical elements of a construction project is time. For clients needing to deliver value to their customers, time is paramount, and the project delivery date is a significant concern for contractors, especially when constructing an airport during its operation, as is discussed in this article. In a paper by Baskoro Adhi and Muslim [6], increased time efficiency through the use of Lean tools was identified as a primary motivating factor in construction. This article explains how Lean tools can be applied to an airport construction project to enhance time efficiency, overcome adaptation barriers, and ensure the delivery of a project on schedule.

2. Literature Review: Lean Construction

The first use of Lean in construction can be traced back to the days of Frank and Lilian Gilbreth and the Motion Study, which was conducted during the examination of bricklaying at construction sites. The concept of Lean construction experienced its greatest development and popularisation in the 1990s, with the term "Lean construction" being adopted in 1993 by the International Group for Lean Construction (IGLC) [7] to describe an approach to designing and carrying out construction activities and minimising waste in materials, time, and effort by achieving the maximum cost-effective value [8]. Further development of Lean construction was backed by the Lean Construction Institute (LCI) in 1997 [9], which to this day continues to promote and continuously print papers on the application of Lean in construction. Lean construction aims to apply the methods, techniques, and tools of Lean to construction projects and processes. The framework for Lean construction was provided back in 1992 in a report by Koskela [10] that laid the foundation for the application of Lean elements to construction projects. Since then, a multitude of elements of the Lean philosophy, such as visual management [11], decentralised decision-making, value stream mapping, etc., have been applied to different construction projects, resulting in a number of benefits, from increased efficiency [12] to fewer risks at construction sites [13]. These elements have been applied to analyse the efficiency of construction works [14], decrease CO_2 emissions [15], improve reliability [16], enhance individual barriers that are important for Lean construction implementation [17], establish a system of continuous improvement and sustainability [18], and enhance SME performance and achieve sustainability [19], affirming that the application of Lean to construction sites is not only plausible but highly beneficial.

3. A3

A3 developed by Toyota represents a structured problem-solving technique that follows a series of steps such as (1) establishing a business context and the importance of a specific problem, (2) describing the current conditions of the problem; (3) identifying the desired outcome, (4) analysing the situation to establish causality, (5) proposing countermeasures, (6) prescribing an action plan for getting the work completed, and (7) mapping out the follow-up process [20]. The technique represents a very powerful tool when applied correctly for productive, dialogue-developing problem-solvers [21]; it helps individuals to learn from one another as it involves a cross-functional team [20]. The A3 should be described as a story [22] that can be easily understood by anybody [20].

According to Alsehaimi et al., Lean can be used to improve construction planning and coordination on work sites [23]. Ballard and Howel argue that planning is the primary focus of construction site organisation [24]. The use of simplified A3 by construction workers has shown productivity increases by removing waste from their processes, which has also enabled companies to address critical areas requiring swift attention. Also, A3 can be used in order to determine the best solution during Last Planner System implementation processes [25].

This paper represents a case study on the application of Lean methods and techniques, more specifically, A3, as one of Lean's main tools [5] that can be used to improve practical issues on worksites [26] through eight steps, from problem definition to follow-up plan, at an airport construction project, with the goal of identifying the possibilities for efficiency improvement of the project while eliminating waste.

4. Research Methodology

Working on the reconstruction and building of new airport facilities is a demanding task. This paper explains the improvement steps of facade works installation of rockwool panels to an area of 6000 m^2. Due to a high number of construction sites performing distinct processes, Lean methodology was used to improve the system and reduce waste.

The methodology that was used in this research was based on the A3 model, accompanied by process improvement thinking and PDCA (Figure 1). The first steps were as follows:

- Obtain some basic knowledge of Lean principles and Lean construction. This was achieved by training with top and middle management together with site supervisors.
- Later, it was important to achieve some quick wins in order to spread the methodology to the other processes on the construction site. To accomplish an improvement, the Lean team decided to go to Gemba and observe the processes on different construction sites.

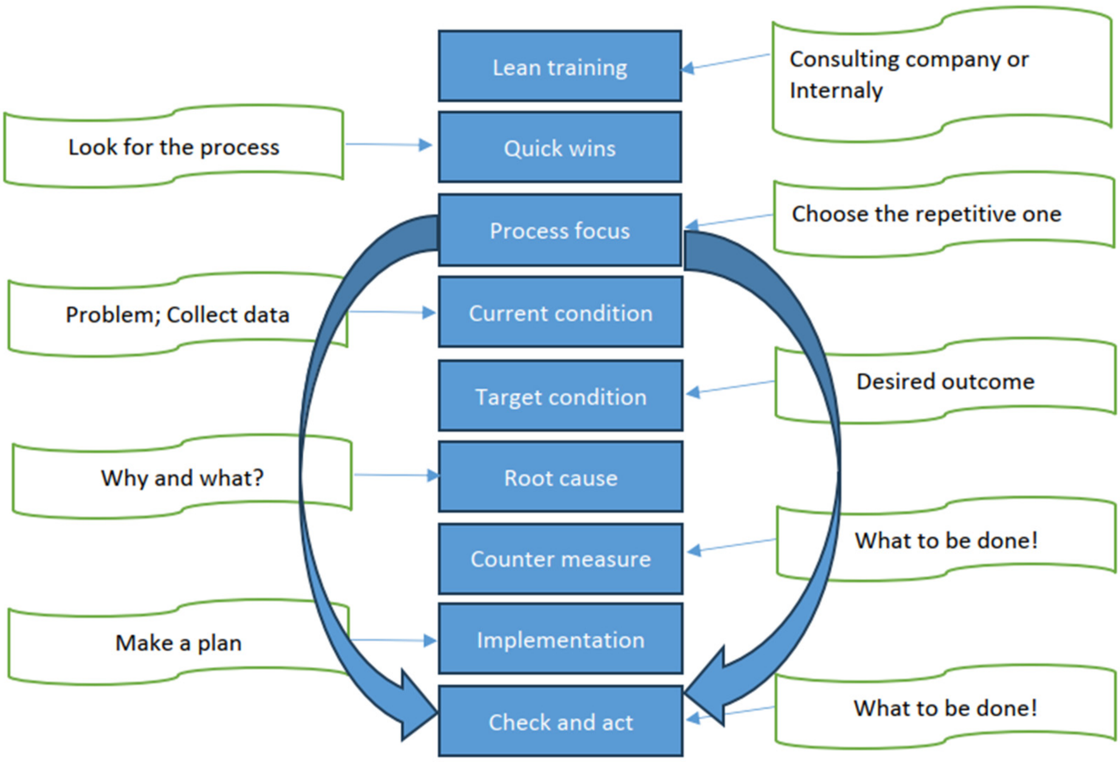


Figure 1. A3 methodology with process improvement and PDCA.

Since practices in construction differ from ones in other industries, in a lot of operations, there are not that many repetitive tasks where takt time, process steps, and standardisation can be implemented. The team observed the process of masonry works, gypsum board installation, facade panel installation, tile work, painting, building foundation processes, steel structural work, etc. For most of them, it was complicated to stick to the routine, standardise the steps, put daily targets in place, and track progress. The main reasons were as follows:

1. Not the same team each day;
2. Not the same structure of the wall (different sizes, different materials, different positions);
3. Different facade panels, sizes, tools, and machines;
4. A lot of pre- and post-activities making a huge impact on the preparation and organisation of the work (material not delivered to the site by the logistics team, shifting operators to different locations on a daily basis, poor planning by supervisors, newcomers, etc.);
5. Many different subcontractors (S/C), making it difficult to achieve any improvement.

Focus: analysing the airport project plan, the team realised that there was an area of 6.000 m^2 of ceiling that had to be covered with rockwool in order to secure the insulation of the building. The work had not started yet, so this was a chance for the team to start focusing on it since it was a long-running and repetitive process, where standard procedures and checklists could be traced to understand future benefits.

The team decided to start with analysing the process of rockwool installation from where the current conditions could be analysed. Obstacles could be seen and understood to propose a target condition. Root cause analysis needed to be conducted to understand the "why and what", from which, an implementation plan could be devised, with results checked and followed up.

4.1. Implementaion of Lean Practice A3—Steps

4.1.1. Problem Statement

The Lean team from the beginning started to observe the team and the process of rockwool installation. The covered area was 6.000 m^2 of ceiling. Most of the area was a flat surface, with some parts with MEP installations and other parts that were hard to reach. The construction work started with 2 teams (Figure 2). Team 1 involved 3 operators on the scissor lift, Team 2 involved two operators on the lift, and both had 3 operators on the ground floor helping them with glue, rockwool, tools preparation, repositioning of the scissor lift, etc.

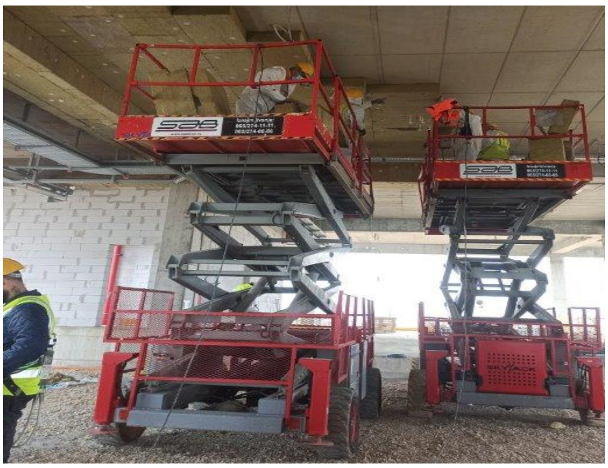


Figure 2. Rockwool installation process.

The problem analysis took one week and the team was able to specify the main problems:

- Operators were new and had never worked on similar operations;
- The worksite was not organised and prepared;
- There was a lack of control;
- The work was very slow and ineffective.

4.1.2. Current Condition

Observing the process by using a stopwatch, a camera, paper, and a pen, the Lean team collected the main facts and metrics of the work presented in Figure 3. As shown, the observation took 8 days. On the first day, the team started to learn how to complete the job since they had never done this work before; they were able to finish 16.2 m^2 of the ceiling, which was covered with rockwool insulation panels. They had been sent from masonry and steel structure work without any training. After 8 days, two teams were able to cover 360.5 m^2 of the ceiling with rockwool panels. One rockwool panel was 0.6 m^2, which meant that they used 600 rockwool panels over 8 days.

Insulation wool ceiling process

Start of observation	April 21, 2023
End of observation	April 28, 2023

Team 1 on lift/ 3 person
Team 2 on lift/ 2 person
3 person on the ground

FOR 8 DAYS, 2 Teams (8 persons)	m2		First day April 21	m2
SUM of area covered with wool panels	360.5		27 wool panels	16.2

Lets remove first day (becayuse they were learning the job)		**m2**
Square meters for 7 days 2 teams		**344.3**
Productivity per day for 2 teams		**49.1**
Productivity - square meters One team (m2/day)		24,6
One wool panel area (m2)		0,6
Installed wool panels per day per One team	wool panel/day	41
Time per one wool panel (-break 60 and start/closing 45)	min/wool panel	9.14
Num. of Wool panels installed for 8 days(one half) 2 teams	wool panels / 8 days	610

Observation from 28th of April - 8 hours

TEAM 1 - 28th of April	min.		Team 2 - 28th of April	min.	
Break time (80) including luch time (45)	125		Break time including luch time	106	
			Machine downtime	150	
Start up and closing	40		Start up and closing	40	
Wool and glue replacement	35		Wool and glue replacement	40	
Relocation of lift	20		Relocation of lift	25	
Time SUM when not instaling wool panels	220	46%	Time SUM when not instaling wool panels/day	361	75%
Instaling wool panels	260	54%	Instaling wool panels	119	25%
1 shift 8 hours	480		1 shift 8 hours	480	

Productivity for 28th of April

	Instaling wool panels (min/day)	Time per wool panel (min)	Num of wool panels instaled	Area m2
Team 1	260	4.3	60.47	36.28
Team 2	119	3.35	35.52	21.31
Productivity for 28 of April		96 wool panels (83 full and 13 in half)		57m2

Team 1 observing the process of wool panels instalation

Process steps	Instaling 1 wool panel	time (sec.)
step 0	taking the wool panel	15
step 1	placing adhesive material on the wool	120
step 2	placing wool on the ceiling	15
step3	driling 1 hole	15
step 4	putting 1 anchor	4
step 5	hammering 1 anchor	4
	2 x repeat (step 3-5)	46 (8)
	Sum	219
Instaling wool panels	**TEAM 1 For 60 wool panels/3 person**	**time min.**
	VA	42
	NVA	423
	NNVA	190

Time when not instaling wool/Team 1/3 person/ one day	time (min.)
Break time (3 person*80) excluding lunch time	240
start up and closing	120
wool and glue replacement	105
relocation of lift	60
Instaling wool panles + time when not instaling	
VA	42
NVA	663
NNVA	475

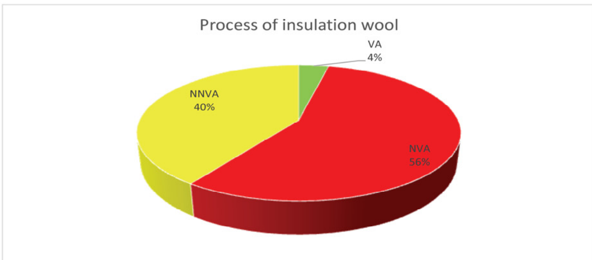


Figure 3. The current condition of the rockwool installation process.

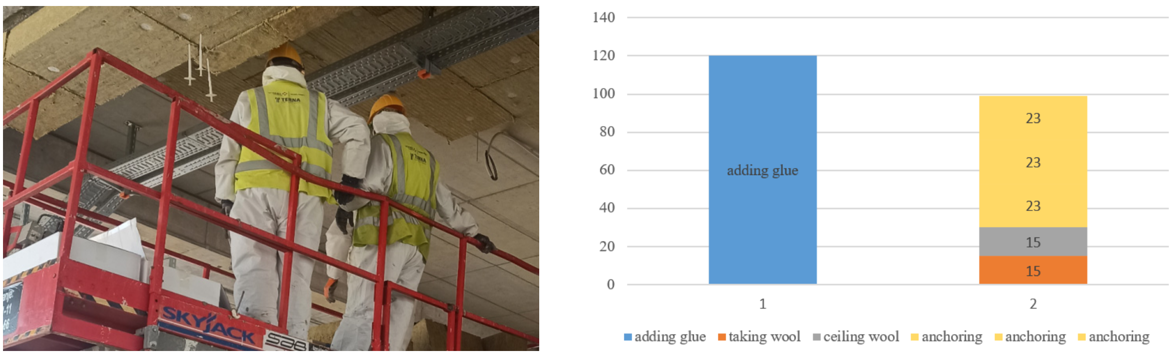
The given data were collected on the last day of observation on the 28th of April, when the operators had learned how to do the job, so this could be used as a starting point for the analysis. Team 1 had 80 min of break time plus lunch break time of 45 min = 125 min and Team 2 had 106 min. The regular break time was only two times 15 min. Due to the lack of supervision, the team was able to spend more time on breaks. The team was taking 40 min to start up the machine, prepare the site, and close the site. To replace the glue, bring the rockwool panel to the scissor lift, and relocate the lift, the teams needed approximately 60 min. Summarising all the data for one shift, Team 1 spent 220 min and Team 2 spent 361 min (this team had a machine break time of 150 min) on these activities (activities that did not add any value); only 260 min for Team 1 and 119 min for Team 2 were spent installing the rockwool panels on the ceiling. On this day, Team 1 covered an area of 36.28 m^2 (60 rockwool panels) in 60 min, which meant that it took them 4.3 min to install one rockwool panel; Team 2 covered 21.31 m^2 in 19 min, which meant that it took them 3.35 min per rockwool panel.

The process of installation for one rockwool panel is presented in Figure 3. On the scissor lift, there were 3 operators. The first step was taking the rockwool panel (15 s) from the ground and putting it on the small table so that the glue could be placed on the rockwool. The second step was putting the glue on the rockwool (120 s). During these 2 operations, only one operator was working, and the other 2 were watching (this meant 2 × 15 s + 2 × 120 s = 270 s of pure waste—NVA). Then, in step 3, two operators brought the panel to the ceiling (15 s), while a third one took the drill machine to start drilling the holes. The first operator drilled one hole (15 s); then, he put the drill machine on the ground and took one anchor (4 s) and a hammer (4 s) to install the rockwool on the ceiling. He proceeded with the same steps afterwards. It took three holes to install the rockwool on the ceiling. The whole process took 219 s to install one rockwool panel.

Excluding the time for Team 1 doing the preparation, having breaks, and relocating the lift and focusing only on the time when the team was working on the scissor lift installing the rockwool, in one day, 3 operators were able to install 60 rockwool panels, on which they spend 42 min (VA) on value-added activities, 423 min on pure waste (NVA), and 190 min on necessary activities (NNVA). Adding to this all the activities during one shift (break, preparation, etc.), the team spent 663 min on pure waste (65% of the time), 475 min on necessary wasted activities (40%), and only 42 min on value-added activities (4%).

4.1.3. Target Condition

As described in step two of A3, the two main activities took most of the time. One activity was the operator taking the rockwool panel and putting the adhesive material on its surface. This activity usually took 2 min. During this time, two operators were watching (Figure 4).



(**a**) (**b**)

Figure 4. (**a**) Pure waste of two operators. (**b**) Target condition.

To improve the process, the target condition was to perform two operations at the same time. One operator added the glue to the rockwool surface while the other anchored the rockwool to the ceiling, so the whole process could take up to 2 min.

4.1.4. Root Cause Analysis

Observing the process and focusing on Man, Machine, Method, Material, and Environment, the main root causes are shown in Figure 5:

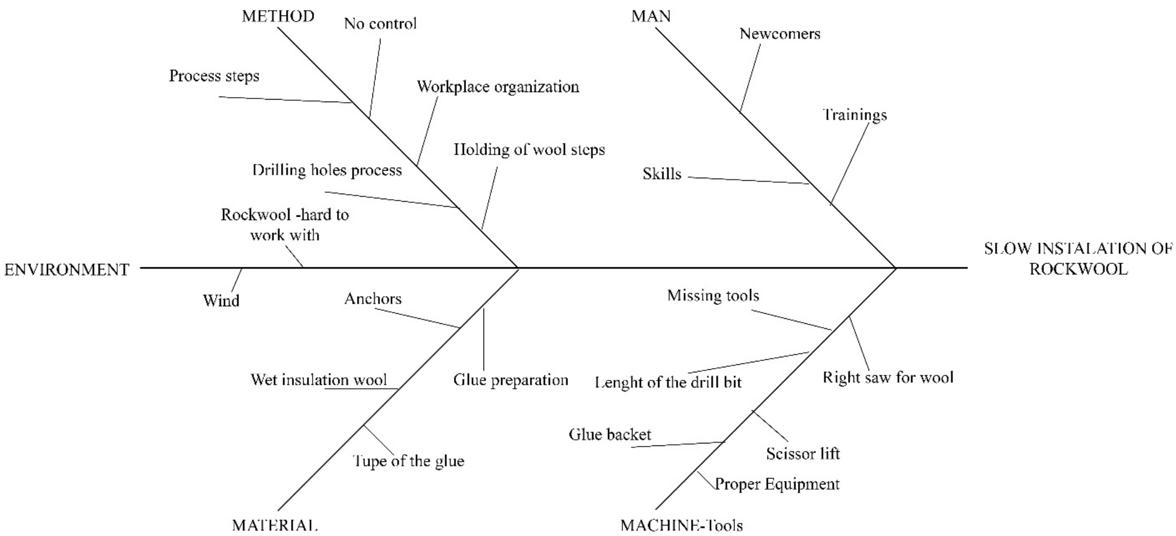


Figure 5. Root cause analysis.

Man—The operators on the construction site. The main construction company had around 60 in-house operators for the different types of work. Usually, it was expected that the operators work on most of them. A lot of operators were inexperienced in jobs like rockwool insulation panel installation; some operators had never been involved in any construction sites before. Therefore, with the lack of training and skills, the operators were not able to provide good results and efficiency.

Method—As described earlier, the process of rockwool installation is not standardised, and it was left to the inexperienced operators to select the best technique and steps to carry it out. Starting from the initial steps, the preparation work where operators had to prepare the rockwool seemed to be not efficient enough. Usually, the glue and the rockwool were being prepared from the moment when operators from the lift did not have more material to work with. Then, they waited for the glue and the rockwool to be unpacked, prepared, etc.

When everything was prepared, two operators held the rockwool all the time, while one operator drilled three holes in the concrete for the anchors. He drilled only one hole at a time, put the drill machine down, rook a hammer and an anchor, and bonded the rockwool to the ceiling. Then, he again took the drill machine to drill the second hole, put the drill down, took the hammer and anchor, and bonded the second part of the rockwool. The third time followed the exact same steps.

The process had no control. Nobody was checking the progress of the team, the correct use of the tools and materials, the following of work instructions, etc.

Machine tools—The team did not use the proper tools for the work. The saw for cutting the rockwool (when needed) had to be a specific one with a sharp edge so it could pass easily through the rockwool. The size of the drill bit had to be small enough in order to put an appropriate anchor inside the concrete ceiling. The lack of tools, such as a measuring meter, drill bits, a drill blocker, and a hammer, had a huge impact on the productivity of the work. The scissor lift was an old one and there was no maintenance plan. When the lift was broken, it was fixed with temporary measures, which meant that the same problem arose all over again.

Material—Some rockwool panels were left in the rain, so it was hard to work with them. In some cases, the team used the wrong short-length anchor. When preparing the glue, the exact amount of water and the correct type of glue for rockwool had to be used. On several occasions, the team made the wrong glue mixture and even used the wrong type of glue.

Environment—The work took place in an open-space area in front of aeroplanes with no wind cover. The rockwool panels were a very particular material and one needed to use suitable equipment like clothes, glasses, eye drops, etc.

4.1.5. Counter Measures

5S—The worksite was in a bad condition. Tools, materials, and dirt were all around the area, left on the ground. The idea was to implement some parts of the 5S tool to organise and sort the site:

Give proper tools to the operators—as described earlier, each team needed to have all the tools needed for the job.

Train the operators—it was necessary to train the operators on how to add glue to the surface of the rockwool, how to do anchoring, how to drill properly, and how to hold the rockwool.

The scissor lift replacement—since the lifts were old and there was no proper maintenance, the suggestion was to bring new ones and repair some old parts from the ones that were to stay.

Rearranging the process steps—two main operations were conducted at the same time and improved.

It was necessary to put in place a daily routine/follow-up once the improvement was in place. A routine was put in place of how the operation was to be run and this was followed-up on.

Prepare the site and the resources—it was necessary to organise and prepare the bottom level in order to gain some time and cut down on waiting.

4.1.6. Implementation Plan

As shown in Table 1, the first step was to organise a workshop together with the team leaders, the site supervisor, and the frontline operators to discuss the process in detail and understand the steps, propose new solutions and ideas, and start the implementation. It was important to involve all of them and not just push ideas from the Lean team in order to sustain the system and make them the owners of it.

Table 1. Implementation plan for the improvement of the rockwool process.

What	Who	When
Brainstorm the process—pick the best ideas	All involved	11/5
Order proper materials and tools and fix the machinery	Foreman	12/5
Organise the worksite—holders for tools and equipment	Maintenance team	20/5
Train the operators—new process steps	Team leader	21/5
Put daily checks in place	Supervisor	Daily
Sustain the process, following up weekly	Supervisor	Weekly

4.1.7. Check the Results of the Implementation Steps

A lot of great ideas came from the team, which were implemented and tested (Figure 6). New tools were bought, a scissor lift was fixed, and another one was replaced. The team had a huge issue with bending all the time when taking the glue out of a bucket that was on the floor. Operators needed to bend down 8 times per rockwool panel. The team installed around 50 rockwool panels per day, which meant that 400 times the operator bent down for the glue. A table was made to put the glue bucket at the appropriate height, so there was no need for extra motion.

Figure 6. Improvements in the rockwool process.

The 5S tool helped the team make a new holder for the drill bit and a holder for anchors and hammer. Before, these were scattered on the floor, so a lot of time was wasted searching for tools and reaching out for them. The area was cleaned at the end of the shift each day. The operator on the ground prepared the rockwool with an extra bucket of glue in order to save time.

To free one operator from the site, a stick was used to hold the rockwool. By holding the rockwool in this way, one operator was able to drill holes while another one placed the glue on the rockwool surface.

A drill jig and coloured tape were used to drill holes at the proper length. Without it, the team spent more time and effort drilling deeper holes.

The improvement results are shown in Table 2 and Figure 7.

Table 2. Results of the improvements.

What	Before	After
# of times operators bent down/day	480	0
Time spent on holding the panel/2 operators	240 min	0
Break time for 3 operators	240 min	90 min
Takt time per rockwool panel (average team 1, 2)	3.82 min	2.1 min
Area covered per team/day	24.9 m^2	60 m^2

As shown in Table 2 and Figure 7, productivity doubled from 30 m^2 per team per day to 60 m^2/day. A lot of hard motion steps were eliminated: with the use of the stick, the operators were released from holding materials with their hands above their head, and the break time was specified and written down—an exact time of two times 15 min, so no room was left for variation.

Also, in Figure 7, it can be seen that only 2 operators were needed to run the process, not 3 as before. Furthermore, two main operations could be performed at the same time, so there was no need to waste the time of 2 other operators.

Before implementation of imrovement

Process steps	Instaling 1 wool panel	time (sec.)	Person involved	People wait	Time waste
step 0	taking the wool panel	15	1	2	30
step 1	placing adhesive material on the wool	120	1	2	240
step 2	placing wool on the ceiling	15	2	1	15
step3	driling 1 hole	45	1	2	90
step 4	putting 1 anchor	12	1	2	24
step 5	hammering 1 anchor	12	1	2	24
	Sum	219	3.65 min/wool		
staling wool pan	TEAM 1 For 60 wool panels/3 person	time min.			
	VA	42			
	NVA	423			
	NNVA	190			

Time when not instaling wool/Team 1/3 person/ one day	time (min.)
Break time (3 person*80) excluding lunch time	240
start up and closing	120
wool and glue replacement	105
relocation of lift	60
Instaling 60 wool panles/day + time when not instaling	
VA for 60 wool panels	42
NVA VA for 60 wool panels	663
NNVA VA for 60 wool panels	475

After implementation of improvement

Process steps	Instaling 1 wool panel	time (sec.)	Person	People wait	Time waste
step 0	taking the wool panel	15	Operator 1	0	
step 1	placing adhesive material on the wool	100	Operator 1	0	
step 0	placing wool on the ceiling	15	Operator 1 and 2	0	
step1	driling 3 hole	45	Operator 2	0	
step 2	putting 3 anchor	12	Operator 2	0	
step 3	hammering 3 anchor	12	Operator 2	0	
step 4	instaling and removing the supporting stick	46	Operator 2	0	
	Sum	130	2.1 min/wool		
staling wool pan	TEAM 1 For 60 wool panels/2 person	time min.			
	VA	42			
	NVA	0			
	NNVA	218			

Time when not instaling wool/Team 1/3 person/ one day	time (min.)
Break time (2 person*45) excluding lunch time	90
Preparing the material	120
start up and closing	120
wool and glue replacement	105
relocation of lift	60
Instaling 100 wool panles + time when not instaling	
VA for 100 wool panels	70
NVA for 100 wool panels	90
NNVA for 100 wool panels	623

Figure 7. Observation before and after.

After analysing the results, it was important to notice if there was no improvement or if more waste could be eliminated in order to go back and focus on the process step, understand it more, and change the implementation plan, following the principle of the PDCA cycle and seeking perfection.

4.1.8. Follow-Up

The main problem for the supervisors and managers was how to tell if the process was running smoothly. Therefore, a checklist was created to be able to control the site and make sure that everyone was following what had been agreed upon. A weekly follow-up was created to analyse each step, target, goal, and plan and improve the system even more. The checklist is shown in Figure 8 and it was implemented in each workplace.

Daily check of the resources and work methods

		Date															
Ref.Num.	Opis	19.5	20.5	21.5	22.5	24.5	25.5	26.5	27.5	28.5	29.5	31.5	1.6	2.6	3.6	4.6	5.6
1	The glue stands on a stand /table small dimensions made of styrofoam																
2	They all have an adequate saw																
3	All have a 310/250/10 mm drill bit																
4	Everyone has a meter																
5	Everyone has a stick and uses it for the ceiling																
6	All have a brightly colored border on the drill / tape																
7	The anchors and hammers are stored in a large bucket attached to the scaffolding / elevator																
8	Everyone has a drill hanging around the workplace / no floor																
9	The saw stands stabbed in wool or the base of a bucket with glue / no floor																
10	Everyone uses a large bucket of glue																
11	Everyone has a bucket of glue ready downstairs during the day																
12	Everyone is storing glue around the work place																
13	They all have wool ready (nylon removed) under the scaffolding																
14	Put the number of pieces of wool adequately space on scissors or scaffolding																
15	The extension cable is hung somewhere on the scaffolding so that it does not interfere during operation																
16	Stairs or wool panels are used as a base for adding material																
17	Where possible, two / three holes are drilled at the same time																
18	At the end of the day the workplace is kept tidy / lift scaffolding and surroundings																
19	Mesh and glue is on stocks at workplace																
	Quantity of wool per team / per day																
	Tim num.																
	Tim num.																
	Tim num.																
	Tim num.																
	Tim num.																
	Sum																
	Quantity of mesh and glue instaled per team / per day																
	Tim num.																
	Tim num.																
	Tim num.																
	Sum																

Figure 8. Daily checklist/follow-up.

Each day, team leaders had to write down how many rockwool panels they had installed. During the day, the supervisor, foreman, or any manager could easily come and check the process. They could check if the operators were using the stick to hold the rockwool; whether the glue was prepared in the bucket on the ground; if they were using the table for the glue bucket; whether the operators were using the drill, hammer, and anchor holders; and if they had the necessary tools around them. The team foreman had the task of checking this and completing training with someone if they were not following the routines and procedures.

The complete A3 process flow was usually summarised in one document to create a precise analysis of the problem solved and the results achieved. It was also archived as an implemented A3 process improvement (Figure 9).

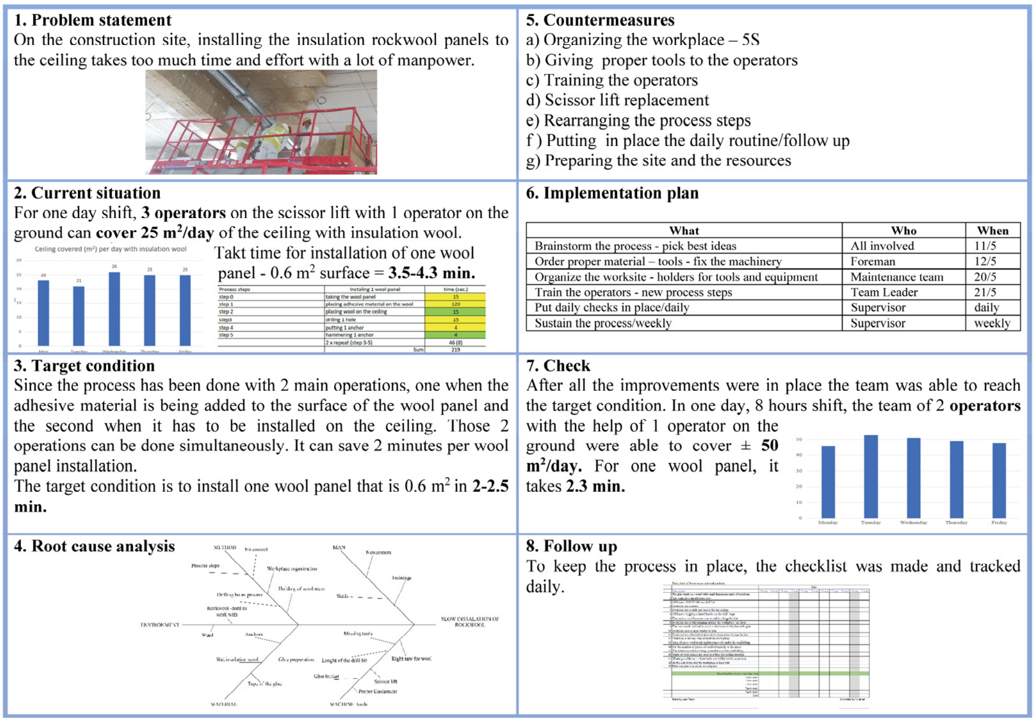


Figure 9. Summarised A3 process flow.

5. Results and Discussion

The Lean team observed the process of rockwool installation over eight days. Initial observations indicated that the operators, who had no prior experience with rockwool installation, were inefficient. On the first day, the team managed to cover only 16.2 m^2 of the ceiling. By the eighth day, they improved slightly, covering 360.5 m^2. Key findings from the observation period are summarised in Figure 3 and they are as follows:

- Team 1 had significant downtime, with 125 min spent on breaks and 220 min spent on non-value-added activities.
- Team 2 had even more downtime due to machine issues, spending 361 min on non-value-added activities and only 119 min on value-added activities.
- The average time to install one rockwool panel was 4.3 min for Team 1 and 3.35 min for Team 2.

Additionally, data from Table 2 and Figure 7 further highlight inefficiencies and areas for improvement:

- Analysis of time loss—both teams experienced substantial time losses due to inadequate process standardisation and frequent equipment malfunctions. Specifically, Team 1 lost 47.6% of their time to non-value-added activities, while Team 2 lost 55.5%.

- Productivity metrics—the productivity rate, measured in m^2 installed per hour, showed a gradual improvement over the observation period. Team 1′s productivity increased from 0.54 m^2/h on the first day to 6.01 m^2/h by the eighth day, while Team 2′s productivity improved from 0.48 m^2/h to 4.94 m^2/h.

The primary inefficiencies observed stemmed from several root causes:

1. Inexperience and lack of training—operators were not adequately trained in rockwool installation, leading to slow progress and significant downtime.
2. Poor process standardisation—the process was not standardised, resulting in inconsistent performance and unnecessary delays. For example, the method of drilling holes and anchoring panels was inefficient, with operators repeatedly picking up and putting down tools.
3. Inadequate tools and equipment—the teams lacked proper tools and the scissor lift was frequently out of order, further slowing down the work.
4. Environmental factors—the open-space work environment exposed the materials to adverse conditions, affecting the quality of the work.

To address these issues, several countermeasures were proposed and implemented:

- Training and process standardisation—operators received training on efficient rockwool installation techniques and a standardised process was introduced.
- Improved tools and equipment—new tools were provided and maintenance schedules for the scissor lift were established to prevent breakdowns.
- Environmental controls—measures were taken to protect materials from the elements, ensuring better working conditions and material quality.

These interventions resulted in noticeable improvements. By standardising the process and ensuring that operators were well-trained and equipped, the efficiency of the rockwool installation increased significantly. Future work should focus on continuous improvement through regular training and process reviews to maintain high efficiency and reduce waste.

This innovative method not only enhances process efficiency but also sets a precedent for future Lean implementations in construction projects. Many of the research papers cited in this study [4–6,8,17,27] were based on theoretical approaches, using questionnaires, simulation games, and literature reviews to support and confirm the study. This paper, however, is based on a real case study, where the problem was detected and a methodology was developed and implemented on a work site. It provides real data and demonstrates the benefits of Lean tools.

Only a few papers were found in the literature where Lean construction tools and A3 were used to increase productivity and improve process flow in the construction industry. Many of these papers show a lack of application and understanding of A3 in construction projects [28–31]. One such paper [32] explains the use of an A3 report to improve lead times in a pavement process at a construction site but does not present target conditions, root cause analyses, countermeasures, and follow-ups as the main steps of the A3 report.

This is the first paper to describe in full the implementation of the Lean tool A3 in the construction industry to improve process productivity, proposing a new methodology that addresses the barriers encountered during the Lean tool implementation process. The methodology developed in this study, which combines the A3 tool and the PDCA cycle, represents a pioneering approach in the construction industry, where the application of Lean tools is scarce.

6. Conclusions

Reviewing the literature, it was found that Lean thinking and A3 have mainly been applied to the manufacturing industry. Since its first application in the construction industry, the A3 approach has rarely been used. Only a few articles cited in this paper can be found in the literature. In the case study that was examined in this paper, it was shown that the application of the A3 methodology along with other Lean elements such as Gemba walks and 5S in construction can increase productivity, confirming the positive impacts of the A3 methodology on construction that have been demonstrated in previous papers [27,32]. This was validated through the problem of rockwool installation at an airport, where the amount of work completed in one day was doubled, with the time needed to install one panel reduced almost by half and the number of workers required for the installation also reduced. The results of the actions that were applied confirm that Lean can improve productivity in construction and that the A3 methodology conforms to the construction industry.

This study presents several positive contributions to the field:

- Thorough Analysis: Problems in the existing process were clearly identified, including the lack of standardisation, inadequate equipment, insufficient training, and unfavourable working environment.
- Practical Interventions: Specific measures were proposed and implemented, such as training, process standardisation, equipment and tool improvements, and the protection of materials from adverse conditions.
- Measurable Results: Quantitative results of the improvements were presented, such as the reduction in the time required to install a single panel and increased productivity, clearly demonstrating the effectiveness of the implemented measures.
- Systematic Approach: The A3 methodology and the PDCA cycle (Plan–Do–Check–Act) were utilised, enabling a systematic and iterative approach to process improvement.

This study highlights several practical implications for the construction industry:

- Increased Productivity: Implementing Lean methodology in the construction industry can significantly increase productivity. As demonstrated in this study, productivity doubled due to process standardisation and employee training.
- Improved Quality: Through standardised processes and worker training, the quality of work improved. Fewer mistakes and a reduced need for rework resulted in a higher-quality final product.
- Site Safety: The application of 5S tools and workplace organisation can enhance employee safety. A clean and organised construction site reduced the risk of accidents and injuries.
- Continuous Improvement: The implementation of the PDCA cycle promoted a culture of continuous improvement on the construction site. Regular reviews and analyses ensured ongoing process enhancement and adaptation to new conditions and challenges.

This research provides significant theoretical implications for the field:

- Expansion of Lean Methodology Application: This study demonstrates that Lean principles, which have predominantly been applied in the manufacturing industry, can also be successfully implemented in the construction industry. This opens the door for further research and application of the Lean methodology in other sectors.
- Validation of A3 Methodology: This study confirms the effectiveness of the A3 methodology in solving problems within the construction industry. This approach can become a standard tool for problem analysis and resolution in construction.
- Interdisciplinary Approach: The combination of Lean tools such as 5S, Gemba, and the PDCA cycle with construction processes shows the value of this approach in addressing complex problems.

Limitations: Key limitations include the specificity of the environment and conditions on construction sites, such as unforeseen weather conditions that can affect work, and the availability of resources like tools and equipment. Additionally, limitations involved the specific characteristics of teams and operational practices within the organisation, which could have influenced the implementation of the proposed measures.

Future Research Directions: Several areas for future research are suggested. First, further studies can focus on a detailed analysis of the long-term effects of the implemented changes, particularly in terms of maintaining improvements in productivity and work quality (longitudinal studies). Second, future research can explore the application of advanced technologies such as process digitalisation (e.g., BIM and IoT technologies) to further optimise construction processes and increase efficiency. Third, future research can investigate how socioeconomic factors and human resource management impact the successful implementation of Lean principles in the construction industry. Finally, it is important to explore the potential to apply Lean methodology to different types of construction projects and environments to generalise results and identify best practices applicable in a broader context within the construction industry.

Managers on construction sites now have a clear methodology on how to implement the most important Lean tools, thereby improving the efficiency and effectiveness of their production processes.

This research can provide valuable insights to both practitioners and researchers for further improving processes in the construction industry, with a focus on continuous performance and efficiency enhancement.

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References

1. Flyvbjerg, B.; Holm, M.K.S. What causes cost overrun in transport infrastructure projects? *Trans. Rev.* **2004**, *24*, 3–18. [CrossRef]
2. Dauda, J.A.; Ajayi, S.; Omotayo, T.; Oladiran, O.O.; Ilori, O.M. Implementation of lean for small-and medium-sized construction organisational improvement. *Smart Sustain. Built Environ.* **2023**, *in press*. [CrossRef]
3. Emuze, F.A. Qualitative Content Analysis from the Lean Construction Perspective: A Focus on Supply Chain Management. *Acta Struct.* **2012**, *19*, 1–18. Available online: https://www.ajol.info/index.php/actas/article/view/85415 (accessed on 10 June 2024).
4. Moradi, S.; Sormunen, P. Implementing Lean Construction: A Literature Study of Barriers, Enablers, and Implications. *Buildings* **2023**, *13*, 556. [CrossRef]
5. Sánchez, O.; Revuelta, M.P.; Gómez-Cabrera, A.; Salazar, L.A. Paper Planes for Teaching Construction Production Systems Based on Lean Tools: Continuous Improvement Cells and 5S. *Buildings* **2023**, *13*, 558. [CrossRef]
6. Adhi, A.B.; Muslim, F. Development of Stakeholder Engagement Strategies to Improve Sustainable Construction Implementation Based on Lean Construction Principles in Indonesia. *Sustainability* **2023**, *15*, 6053. [CrossRef]
7. Koskela, L.; Ballard, G.; Howell, G.; Tommelein, I. The foundations of lean construction. In *Design and Construction: Building in Value*, 1st ed.; Best, R., Valence, G., Eds.; Butterworth Heinemann: Oxford, UK, 2002; pp. 211–226.
8. Babalola, O.; Ibem, E.O.; Ezema, I.C. Implementation of lean practices in the construction industry: A systematic review. *Build. Environ.* **2019**, *148*, 34–43. [CrossRef]
9. Tezel, A.; Nielsen, Y. Lean construction conformance among construction contractors in Turkey. *J. Manag. Eng.* **2013**, *29*, 236–250. [CrossRef]
10. Koskela, L. *Application of the New Production Philosophy to Construction*; Stanford University: Stanford, CA, USA, 1992.
11. Sacks, R.; Treckmann, M.; Rozenfeld, O. Visualization of Work Flow to Support Lean Construction. *J. Constr. Eng. Manag.* **2009**, *135*, 1307–1315. [CrossRef]
12. Thomas, H.R.; Horman, M.J.; minchin, R.E.; Chen, D. Improving Labor Flow Reliability for Better Productivity as Lean Construction Principle. *J. Constr. Eng. Manag.* **2003**, *129*, 251–261. [CrossRef]

13. Issa, U.H. Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alex. Eng. J.* **2013**, *52*, 697–704. [CrossRef]
14. Juszczyk, M. Construction Work Efficiency Analysis-Application of Probabilistic Approach and Machine Learning for Formworks Assembly. *Appl. Sci.* **2023**, *13*, 5780. [CrossRef]
15. Fuenzalida, C.; Fischer, B.; Arroyo, P.; Salvarierra, J.L. Evaluating Environmental Impacts of Construction Operation before and after the Implementation of Lean Tools. In Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA, 18–24 January 2016.
16. Brodetskaia, I.; Sacks, R.; Shapira, A. Stabilizing Production Flow of Interior and Finishing Works with Reentrant Flow in Building Construction. *J. Constr. Eng. Manag.* **2013**, *139*, 665–674. [CrossRef]
17. Moyo, T.; Chigara, B. Barriers to lean construction implementation in Zimbabwe. *J. Eng. Des. Technol.* **2023**, *21*, 733–757. [CrossRef]
18. Cunha, F.; Dinis-Carvalho, J.; Sousa, R.M. Performance Measurement Systems in Continuous Improvement Environments: Obstacles to Their Effectiveness. *Sustainability* **2023**, *15*, 867. [CrossRef]
19. Abdullah, A.; Saraswat, S.; Talib, F. Impact of Smart, Green, Resilient, and Lean Manufacturing System on SMEs' Performance: A Data Envelopment Analysis (DEA) Approach. *Sustainability* **2023**, *15*, 1379. [CrossRef]
20. Shook, J. Toyota's Secret: The A3 Report. *MIT Sloan Manag. Rev.* **2009**, *50*, 30–33.
21. Sobek, D.K.; Smalley, A. *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System*, 1st ed.; Productivity Press: Boca Raton, FL, USA, 2008.
22. Matthews, D.D. *The A3 Workbook: Unlock Your Problem-Solving Mind*, 1st ed.; CRC Press: New York, NY, USA, 2010.
23. Alsehaimi, A.O.; Fazenda, P.T.; Koskela, L. Improving construction management practice with the Last Planner System: A case study. *Eng. Constr. Archit. Manag.* **2014**, *21*, 51–64. [CrossRef]
24. Ballard, G.; Howell, G. Shielding Production: Essential Step in Production Control. *J. Constr. Eng. Manag.* **1998**, *124*, 11–17. [CrossRef]
25. Gómez-Cabrera, A.; Salazar, L.A.; Ponz-Tienda, J.L.; Alarcón, L.F. Lean Tools Proposal to mitigate Delays and Cost Overruns in Construction Projects. In Proceedings of the 28th Annual Conference of the International Group for Lean Construction (IGLC28), Berkeley, CA, USA, 6–12 July 2020. [CrossRef]
26. Koskela, L.; Broft, R.D.; Pikas, E.; Tezel, A. Comparing the Methods of A3 and Canvas. In Proceedings of the 28th Annual Conference of the International Group for Lean Construction (IGLC28), Berkeley, CA, USA, 6–12 July 2020. [CrossRef]
27. Saad, N.M.; Al-Ashaab, A.; Shehab, E.; Maksimovic, M. A3 thinking approach to support problem solving in Lean Product and Process Development. *Adv. Concurr. Eng.* **2013**, 871–882. [CrossRef]
28. Ankomah, E.N.; Ayarkwa, J.; Agyekum, K. A theoretical review of lean implementation within construction SMEs. *J. Constr. Proj. Manag. Innov.* **2017**, *7*, 1675–1688. Available online: https://hdl.handle.net/10520/EJC-84c806440 (accessed on 10 June 2024).
29. Xing, W.; Hao, J.L.; Qian, L.; Tam, V.W.; Sikora, K.S. Implementing lean construction techniques and management methods in Chinese projects: A case study in Suzhou, China. *J. Clean. Prod.* **2021**, *286*, 124944. [CrossRef]
30. Ankomah, E.N.; Ayarkwa, J.; Agyekum, K. Status of lean construction implementation among small and medium building contractors (SMBCs) in Ghana. *J. Eng. Des. Technol.* **2020**, *18*, 1691–1709. [CrossRef]
31. Singh, S.; Kumar, K. Review of literature of lean construction and lean tools using systematic literature review technique (2008–2018). *Ain Shams Eng. J.* **2020**, *11*, 465–471. [CrossRef]
32. Ko, C.H.; Tsai, P.C. Applying Lean Production A3 to Enhance Construction Work Flow. *Life Sci. J.* **2013**, *10*, 2409–2416.