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LEAN AND SUSTAINABILITY: THREE PILLAR THINKING IN THE PRODUCTION PROCESS

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ABSTRACT

The concepts of Lean Construction and Sustainable Development share certain fundamental objectives, such as reducing waste and increasing value. The aim of this research is to investigate the extent to which the use of lean construction principles can assure increased sustainability in construction projects. This paper will explore the commonalities of these concepts and determine indicators that can be used to express the impact of lean on all three pillars of sustainability: economy, society and environment.

This work is executed as an explorative sample study of what are considered two of the leading companies in using lean construction approaches in the Norwegian construction industry. Semi-structured in-depth interviews of six key contributors were conducted. The work is limited to the production phase of a project, and focuses on sustainability in the process rather than of the product.

The main finding is that lean construction can have a positive impact on selected indicators for sustainability. This impact is primarily related to reduced stress, less sick leave, increased productivity, more efficient use of resources and improved quality. Lean construction observably has an evident impact on all three pillars of sustainability, and it should be focused on equating the social, economic and environmental aspects of future work.

KEYWORDS

Lean Construction, Lean and Green, Sustainability, Sustainable Development, Production Process

INTRODUCTION

Anthropogenic climate changes and global warming has become extremely important topics during the last decades. The concept of Sustainable Development has occurred as an initiative to improve social, economic and environmental conditions. The Brundtland commission was the first to define Sustainable Development in 1987, defining it as

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"*development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs*" (Kates et al. 2005).

The building sector uses 40 % of the global energy and contributes to approximately 30 % of the global annual green house gas emissions (United Nations Environment Programme 2009), and therefore has great responsibility and capacity to improve. Because of this, sustainability has become an important term in the construction industry, often referred to as sustainable construction or green building. In parallel the construction industry has experienced a relative decline in productivity compared to other industries (Langlo et al. 2013). The construction industry is in need of better resource efficiency, better productivity, less waste and increased value. Lean Construction can be the means to this end. This paper aims at investigating to what extent lean construction can contribute to better sustainability of construction projects.

This topic has been explored already by different authors such as Bae and Kim (2008), Huovila and Koskela (1998) and Lapinski et al. (2006). Previous literature describes the fundamental similarities between the two concepts. The most obvious connections are related to reducing waste and increasing value. Large parts of the literature explores primarily the environmental aspects of sustainability, such as Carneiro et al. (2012) and Valente et al. (2013). In this paper we have chosen to have a broad perspective looking at all three pillars of sustainability. The goal has been to identify actual connections between lean construction and sustainability. To facilitate this, we have formulated a set of indicators for each of the sustainability aspects. Hence, the research questions that this paper is based on are:

1. Which indicators can be used to show the connection between lean and sustainability?
2. To what extent does lean impact the given indicators?

THEORETICAL FRAMEWORK

Sustainability is a broad term used in many different settings, and has to be used at an appropriate level of abstraction. In social economics one distinguishes between macro and micro economy, where macro economy is giving an overview of the society's economy, while micro economy deals with the economy of individuals or companies (Andresen and Stoltz 2015). If we consider sustainability in the same way, stopping global warming and eliminating poverty can be considered macro level sustainability, while micro level sustainability in this work will be local sustainability in construction projects. Thus, in this work we have chosen to narrow it down to sustainability of the construction project. Improvements in micro level sustainability will contribute positively to the macro level sustainability.

Considering all the phases of a project would be outside the scope of this research, so we have limited the research to the production process of a construction project. Laedre et al. (2015) describes three different levels of sustainability in a project: strategic, tactical and operational. In this work we have concentrated on the operational level, which is the level most compatible with lean construction.

To ensure better sustainability in the construction industry there exists several tools and methods. One of them is BREEAM, which globally is one of the most used environmental certification systems. Green Building or Sustainable Construction does often have an extra cost of design and planning compared to traditional buildings (Lapinski et al. 2006). In addition, a lot of green projects are loaded with rework, delays, changes and overproduction due to bad selection of delivery methods. Waste in the process can limit both the building's and the project's sustainability (Klotz et al. 2007). By identifying waste, sustainable results can be improved through using delivery methods better suited to maximize value, such as Lean Construction. This implies the importance of sustainability in the production process, not just of the building itself.

As already mentioned, others have done research on this subject previously. Huovila and Koskela (1998) investigated this topic early in the lean construction history and explored the fundamental connections. They consider eliminating waste and adding value to the customer as the two most important contributions from lean to sustainability. Eliminating waste and adding value will contribute to sustainability by minimizing resource depletion and pollution.

Campos et al. (2012) investigated the relationship between lean construction and the sustainable maturity of construction companies. They found that principles such as focus on high quality, reduction of waste, flow of information between workers and project managers and continuous improvement are shared between the two concepts. Another interesting point of note was that the two concepts have mutual influence on each other: lean makes projects more sustainable and sustainability is making projects leaner.

Bae and Kim (2008) had a more practical approach, comparing lean methods to sustainability criteria based on a LEED checklist. They summarized the possible impacts from lean on each pillar of sustainability

- Economic impact: possible up front cost reduction, resource savings, operating cost reduction and high performance capability
- Social impact: workplace safety, occupant health, community well-being, loyalty among stakeholders and external image improvement
- Environmental impact: reduced resource depletion, pollution prevention by eliminating waste, and resource preservation

In Horman et al. (2006) they have used a set of social, economic and environmental indicators to compare site-built versus prefabricated buildings. Examples on indicators used are quality, material waste and working conditions. They also use indicators considering other aspects of the life cycle of a building, for example material choices, maintenance costs and deconstruction. The literature review found other authors presenting sustainability indicators for the construction industry, such as Cox et al. (2003), Toor and Ogunlana (2010), Ugwu and Haupt (2007).

METHODOLOGY

The purpose of this work was to find out to what extent Lean Construction can contribute to increased sustainability in construction projects. To do so it was necessary to investigate in what ways Lean Construction impacts the sustainability of construction

projects. A literature review revealed that the concepts share several fundamental principles, but in our opinion a broader and more tangible evaluation would be preferable. To give a complete evaluation of Lean Construction's impact on sustainability, suitable indicators were developed for each of the three pillars of sustainability: social, economic and environmental. Indicators from the literature inspired the indicators chosen in this work, but in the end it was the authors who developed the set of indicators they found most appropriate for this research. There were found to be a lack of social indicators on the micro level of a project, and this area needed further research. The final indicators are presented in Table 1.

Subsequently the indicators were used as a foundation for qualitative data collecting. In-depth interviews were conducted with six key contributors from two of the leading companies using lean construction methods in the Norwegian construction industry. They are among the largest companies concerning turnover and employees, and they both carry out various types of construction and development. As the interviews were semi-structured they took the form of conversations or discussions, including some fixed questions. Following is a selection of questions from the interviews:

- How do you work with lean in your company?
- How do you work with lean in this project?
- What are the actions taken for sustainability in this project?
- How is lean influencing the following indicators for sustainability?
- Have you previously considered the connection between lean and sustainability?

To get valid answers from the interviews, skilled people had to be prioritized. It was a necessity that the informants had knowledge about both lean construction and sustainability. The key contributors interviewed were working as project manager, site manager, design manager, lean coordinator, BREEAM coordinator and H&S/quality/BREEAM coordinator. Most of the informants had corresponding answers, which indicates good reliability of the information.

The information collected from the interviews were processed and evaluated. The recordings of the interviews were listened to several times, and rough transcriptions were made. The authors evaluated the materials looking for similarities and differences. To be able to present the results graphically the qualitative data was quantified through creation of a frequency table with an ordinal scale. The scale ranged from -2, very negative impact, to +2, very positive impact. All the responses on all the indicators were rated. If an informant did not consider one of the indicators, or if the indicator were considered as not being affected by Lean it was rated 0. These numbers were the foundation for a radar chart inspired by a Sustainability Impact Assessment. As there where no negative impacts the chart has a scale from 0 to +2.

RESULTS

The selected indicators were inspired by the literature review. In the end, we composed a new set of indicators better adapted for this research. It was important to have various indicators for all three pillars of sustainability, to obtain a broad point of view. In addition,

as this work is limited to the production process, the indicators had to be relevant to the production process and not the product or the whole life cycle as many of the indicators in the existing literature. The indicators chosen for this research are presented in Table 1 below, while more detailed descriptions of indicators and replies from the interviews are left out due to space issues. How the indicators originated are presented with the results, also due to space limitations.

Table 1: Indicators for sustainability

Social indicators	Economical indicators	Environmental indicators
Sick leave	Number of errors	Material waste
Number of accidents	Productivity	Use of resources
Equality	Profitability	Air pollution
Social dumping	Cost	Transport on site
Stress	Time	Energy use
Overtime	Quality	CO_2 emissions
	Changes	Construction noise

The informants gave different thoughts on how lean construction is influencing the sustainability of projects, through impacting the presented indicators for sustainability. A summary of the interviews is presented in Table 2, 3 and 4 below, one table for each pillar of sustainability. Thus, only the most prominent examples of lean principles or methods, which can impact sustainability, are presented.

Table 2: Social indicators

Indicator	Source/inspiration	Lean impact
Sick leave	Cox et al. (2003)	• Inspiration and motivation to get to work • Responsibility by involvement • Commitment to the group/project • Workers feel important
Number of accidents	Toor and Ogunlana (2010), Chen et al. (2010)	• Less mess • Good routines • Good planning and preparations • Less moving of materials • Daily huddle meetings
Equality	Dhondts and Houtman (1997)	• Having their own workers • Same rules for all actors in the project
Social dumping	Dhondts and Houtman (1997)	• Communication and culture • Continuous improvement between projects
Stress	Dhondts and Houtman (1997)	• Involvement of workers • Visualization and 3D models • Better plans
Overtime	Dhondts and Houtman (1997)	• Predictability • Better planning

On the subject of impact on social indicators involvement, found in Table 2, commitment, good planning and having their own workers stands out as the most influencing factors.

Because of involvement the workers will feel inspired, responsible and motivated about their work. Having their own workers will help the companies achieve a good culture and facilitate continuous improvement and learning. Better planning and visualization gives better predictability and better understanding among the workers.

The economic impacts from lean construction on sustainability, found in Table 3, are mainly related to better planning and involvement. Involvement leads to better planning, gives the workers ownership to the plans and motivates them to minimize use of resources and focus on quality and productivity. This can lead to less errors and changes, which directly leads to lower costs, shorter lead time and higher profitability.

Table 3: Economic indicators

Indicator	Source/inspiration	Lean impact
Number of errors	Toor and Ogunlana (2010), Chen et al. (2010)	• Visualization • Involvement of workers in the planning • Good dialogue • Commitment to other team members
Productivity	Cox et al. (2003)	• Involvement • Ownership to the work • Monday meetings and visual planning • Monitoring of progress • Common and clear goals
Profitability	Cox et al. (2003)	• Right information at the right time • Better planning • Ownership • Having theirs own workers
Cost	Toor and Ogunlana (2010), Chen et al. (2010)	• Less errors gives a cheaper project • Less sick leave is cheaper • Own workers are cheaper in the long run
Time	Horman et al. (2006), Chen et al. (2010)	• Learning and continuous improvement • Visual plans showing progress • Takt-time makes project duration predictable
Quality	Horman et al. (2006)	• Continuous improvements • Ownership • Involvement
Changes	Horman et al. (2006)	• Involvement • Collocation • Lean design phase

The impacts on environmental indicators are shown in Table 4. They are on one hand related to the choice of materials and production methods and on the other hand related to good routines, less mess and ownership. Ownership makes the workers recycle the waste and minimize the use of resources. Choosing prefabricated elements is also affecting construction waste and use of resources. Better resource efficiency is leading to less CO_2-emissions and energy use. Improved planning is influencing the local air pollution, construction noise and transport on site.

Table 4: Environmental indicators

Indicator	Source/inspiration	Lean impact
Material waste	Horman et al. (2006), Chen et al. (2010)	• Prefabrication • Recycling of waste • Ownership and responsibility
Use of resources	Ugwu and Haupt (2007), Chen et al. (2010)	• Prefabrication • Ownership • Better planning and avoiding mistakes
Air pollution	Chen et al. (2010)	• Less mess gives less pollution • Better planning and better methods
Transport on site	Horman et al. (2006)	• Well planned logistics, JIT • Involvement of workers • Continuous improvement and optimization during the project
Energy use	Chen et al. (2010)	• Involvement • Ownership and good routines
CO_2 emissions	Chen et al. (2010)	• Choice of materials • Better resource efficiency • Better planning
Construction noise	Bae and Kim (2008)	• People report unnecessary noise

To better illustrate the impacts from lean construction on sustainability, the impact on the indicators are gathered in Figure 1. This figure is inspired by a SIA, showing impacts within all three pillars of sustainability.

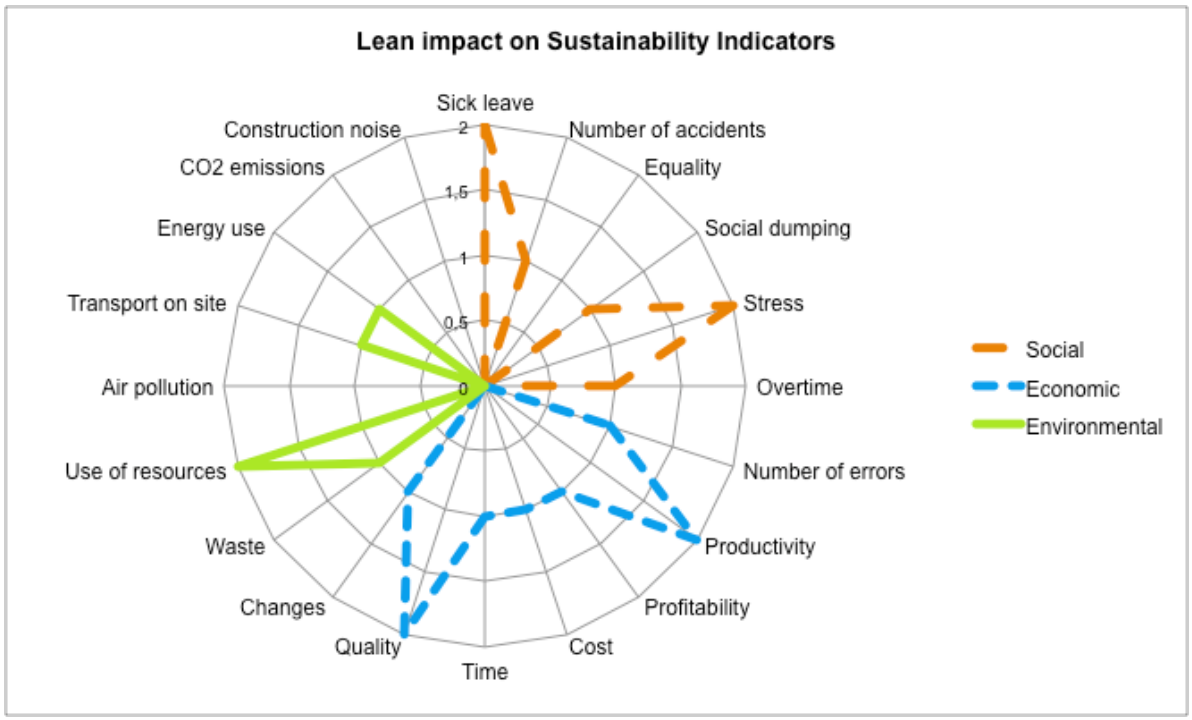

Figure 1: Illustration of lean impacts

As the diagram in Figure 1 shows, the biggest impacts from lean construction on sustainability are found on sick leave, stress, productivity, quality and use of resources. This research shows that lean construction has the least impact on equality, air pollution, CO_2-emissions and construction noise.

DISCUSSION

The selected indicators had a broad approach including indicators for all three pillars of sustainability. This was essential to successfully resolve the questions posed in this research. Some of the indicators need additional specification if they are to be used for quantitative research, even though they were found to be appropriate for this qualitative approach. This study was explorative and the purpose of the indicators were namely to indicate lean construction's impact on sustainability. The indicators were well suited for the research, with a focus on the production process, i.e. the construction process. This does not mean they cannot be used in other settings, as the indicators are considered as quite general. Most of the indicators found in the literature review were concerning the whole life cycle of a building, or the building itself. The indicators from the literature review have been used for a general evaluation of sustainability, while the indicators from Horman et al. (2006) had been used specifically to compare lean and sustainability. Still these indicators had a too wide perspective and too much focus on the product.

When it comes to the results of the interviews it is possible to conclude that lean construction has a positive impact on the three pillars of sustainability. This work did not identify any negative impacts from lean construction on sustainability. The findings are mostly supporting the literature. One exception is that Bae and Kim (2008) indicated that Just-in-Time might lead to increased emissions due to increased traffic, which was denied by several of the informants. They claimed Just-in-Time was beneficial for the sustainability in spite of more frequent traffic, as the logistics would be better organized. Another distinction from Bae and Kim (2008) was that they compared lean methods and tools with sustainability, while the interviews in this research revealed that many of the impacts are caused by values and principles, such as ownership and responsibility.

A challenge with the work was the ambiguity, the fact that none of the impacts on sustainability are solely caused by lean construction. Examples of other factors that could influence the indicators for sustainability are the companies' business strategy and daily practice. In companies using lean construction the values of lean will be implemented in their practice, but some of the values might have been implemented without lean as well. In one way these values will be lean no matter if the company defines them as lean or not.

Several of the informants mentioned that lean and BREEAM are well compatible. A question to consider is whether BREEAM might have a negative impact on lean construction. This could be caused by increased waste due to extra documentation, which will increase the duration of the process, and reduce the productivity. Campos et al. (2012) found that BREEAM made projects leaner, which is contradictory with the previous statement. BREEAM can contribute to making projects leaner by focusing on minimizing use of resources and reducing material waste. Some of the informants said that many of the BREEAM criteria were already obtained thanks to lean practices. Most of the

environmental indicators in this research are coinciding with BREEAM criteria. This suggests that BREEAM is primarily evaluating environmental performance, not complete sustainability.

CONCLUSION

The intent of this research was to investigate to what extent lean can assure more sustainable construction projects, by defining indicators of sustainability and finding how lean affects them. The indicators chosen in this research were suited to show the connection between lean and sustainability in construction projects.

The interviews confirmed what the literature says, that lean construction and sustainability are connected. The most frequently mentioned impacts were related to reduced stress, less sick leave, increased productivity, more efficient use of resources and improved quality. Increased ownership, responsibility, involvement, visualization and improved planning were causing these impacts. Lean Construction observably has an evident impact on all three pillars of sustainability, and it should be focused on equating the social, economic and environmental aspects on future work on sustainability in the construction industry.

Although there was a high degree of agreement between the informants, more interviews would have been beneficial for the reliability of the findings. There were some challenges with the execution of the interviews, as the topic was quite unknown. It required the interviewer to present some background information, which might have influenced the informants. The interviews were semi-structured, however a more structured approach could have insured the informants would consider all the indicators. As an example, the social sustainability indicator equality was not discussed as much as the other indicators. Yet the findings from this work are considered both valid and reliable, and give a good indication as to what extent lean construction has an impact on sustainability.

As this work is entirely qualitative, conducting a more quantitative approach is recommended. For future work one can consider executing more interviews, doing a survey and perhaps modify the indicators. Another option could be to search for quantitative data on the given indicators through a case study, to see if they can confirm what is found in this work.

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