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IMPROVING LABOUR PRODUCTIVITY OF FAST RETROFITTING CONCEPTS OF NETZERO ENERGY HOUSING IN THE NETHERLANDS

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ABSTRACT
The authors examined how to improve the total (onsite and offsite) labour productivity of production and assembling of fast retrofitting concepts in the Netherlands. The authors analysed the collected data of two NetZero energy renovations in which the initial process were quite traditional. In the first case the labour productivity can increase spectacularly by prefabricating the roof. In the second case the providers modernized the process by working in multi-disciplinary teams. No evidence have been found that working in a multi-disciplinary team can increase the labour productivity but the time for realization did decrease.

1 Introduction

In the Netherlands clients and builders are searching for product systems for fast retrofitting of NetZero housing. Organizations such as Social housing associations, contractors, investors, municipalities, etc. who are member of “Stroomversnelling” (rapids) are experimenting with industrialized Net zero retrofitting concepts. Together they have renovated a few dozens of houses built between 1950 and 1980. An important precondition for the renovation is that the households don’t pay more for their housing after the renovation. The rent after the renovation is equal to the rent plus energy costs before the renovation.

Because the retrofitting has to be paid by the savings on the energy bill, investors and providers are searching for new business models. Important aspects to establish a viable business case are the rent (before and after the renovation), the energy costs (before renovation), renovation costs, discount rate, and cost of maintenance and property value (or the estimated selling price at the end of exploitation).

To make the business case attractive for commercial investors, social housing organizations have to look differently to their traditional business. Nowadays social housing corporations use the so-called ‘discounted cash flow method’ in which they base the value of the property on the total life time. However the market value method (fair value method, open market valuation) is closer to fair property values and therefore gives more reliable input for commercial financing.

On the other hand contractors have to look for methods to lower the costs of renovation. Providers are using lean principles, including process optimization, industrialization and changing the mentality of construction workers to lower the costs (Höök, 2008). Step by step contractors change the traditional renovation process into a fast retrofitting concept. Those concepts cost a lot of money and time

though. On the other hand the production and assembly of the fast retrofitting concepts save a lot of money and time so that in the end the fast retrofitting concept of NetZero energy housing should become cheaper than renovating the same NetZero energy housing in the traditional way. Additionally is the time the renovation takes on site because the customer keeps on living in the house during the renovation.

In this paper the authors give an answer to the question: How to improve the labour productivity of production and assembling fast retrofitting concepts? With this answer and the costs of labour, which is out of the scope of this paper, providers can calculate how much they can save on the total cost of their retrofitting concept. And therefore they can conclude if a fast retrofitting concept can reduce the total costs of a renovation.

First this paper discusses the definition of labour productivity and factors that influence labour productivity. After that the labour productivity of two traditional NetZero renovations will be calculated. The characteristics that influence the labour productivity of the two cases will be discussed. In earlier research on both cases researchers made recommendations on how to improve the traditional renovation to a fast retrofitting concept. Measuring the labour productivity, as mentioned in this paper, wasn't the purpose of the researches. Therefore this paper will discuss those recommendations and will calculate the gain in labour productivity when those recommendations are accepted.

2 Definition and factors that affect labour productivity

2.1 Definition of labour productivity

A review of construction journals by Wen Yi and Albert P. C. Chan concludes that there's no agreement about the precise definition of productivity (Yi & Chan, 2014). The definitions differ in which elements productivity includes and they differ in what is meant by high productivity.

Economists and accountants define productivity as the ratio between total input of resources and total output of product. Resource input includes the elements labour, materials, equipment, and overhead. Output can be measured as the total money value of construction put in place. (Hanna, Taylor, & Sullivan, 2005).

$$Productivity = \frac{input\ of\ resources}{output\ of\ product} = \frac{€x}{€y}$$

Equation 1

Construction activities are normally labour-intensive (Song & Abourizk, 2008). That's why in construction project managers and construction professionals often define productivity as a ratio between the two elements: earned work hours and expended work hours, or work hours used. (Hanna, Taylor, & Sullivan, 2005)

$$Productivity\ index = \frac{budgeted\ work\ hours}{actual\ work\ hours} = \frac{x\ hours}{y\ hours}$$

Equation 2

Previous industry studies differ in what is meant by high productivity:

$$Productivity = \frac{output}{input} \quad \text{or} \quad Productivity = \frac{input}{output}$$

Equation 3 *Equation 4*

(Park, Thomas, & Tucker, 2005)

The first equation means that a high output of production with a low input of resources results in a high productivity. The second equation means that a high output of production with a low input of resources results in a low productivity. The second form has been widely used and existing in literature over the years in the construction industry (Park, Thomas, & Tucker, 2005). But project managers and construction professionals in the Netherlands are speaking of high productivity when there is a high output of production with a low input of resources. Therefore this research adopt the first equation. This research will examine how to improve labour productivity. This research compares differences in process between fast retrofitting concepts and traditional NetZero energy renovations. In this comparison the output of both methods is the same: one house, or one part of the house. That's why labour productivity in this research is defined by Equation 5:

$$Labour\ productivity = \frac{building\ parts}{labour\ hours}$$

Equation 5

When observing a traditional renovation a lot of labour will be at the building site. Providers of fast retrofitting concepts use prefab elements and are moving the labour from building site to factories. To make a fair comparison in labour productivity this research defines the offsite labour hours also as labour hours. In this research the definition of labour hours is an (clock)hour spent (by the providers) on a manual worker for the complete renovation. That also means waiting time for instance.

2.2 Factors that affect productivity

There are numerous factors which influence labour productivity. These factors could be classified as (Shehata & El-Gohary, 2011):

- **Industry related factors** such as complexity and repetition of design, codes, laws and regulations, job duration, size of the job and type of job, weather and seasonality, site location.
- **Management related factors** such as planning and scheduling, leadership, motivations and communication.
- **Labour related factors** such as labour skill, motives and labour availability.

Farnad Nasirzadeh and Pouya Nojedehi divided the factors in another way. They depict the affecting factors of labour productivity as lack of working area, skilfulness and project management efficiency as seen in Figure 1. (Nasirzadeh & Nojedehi, 2012). In this figure an arrow with an "+" means: "has a positive influence on…."

Not every possible factor that affects the labour productivity is within this model. For instance the influence of complexity of design, regulations and availability of labour are not is this model. Nevertheless this model gives a good base to give insight in factors that influence labour productivity.

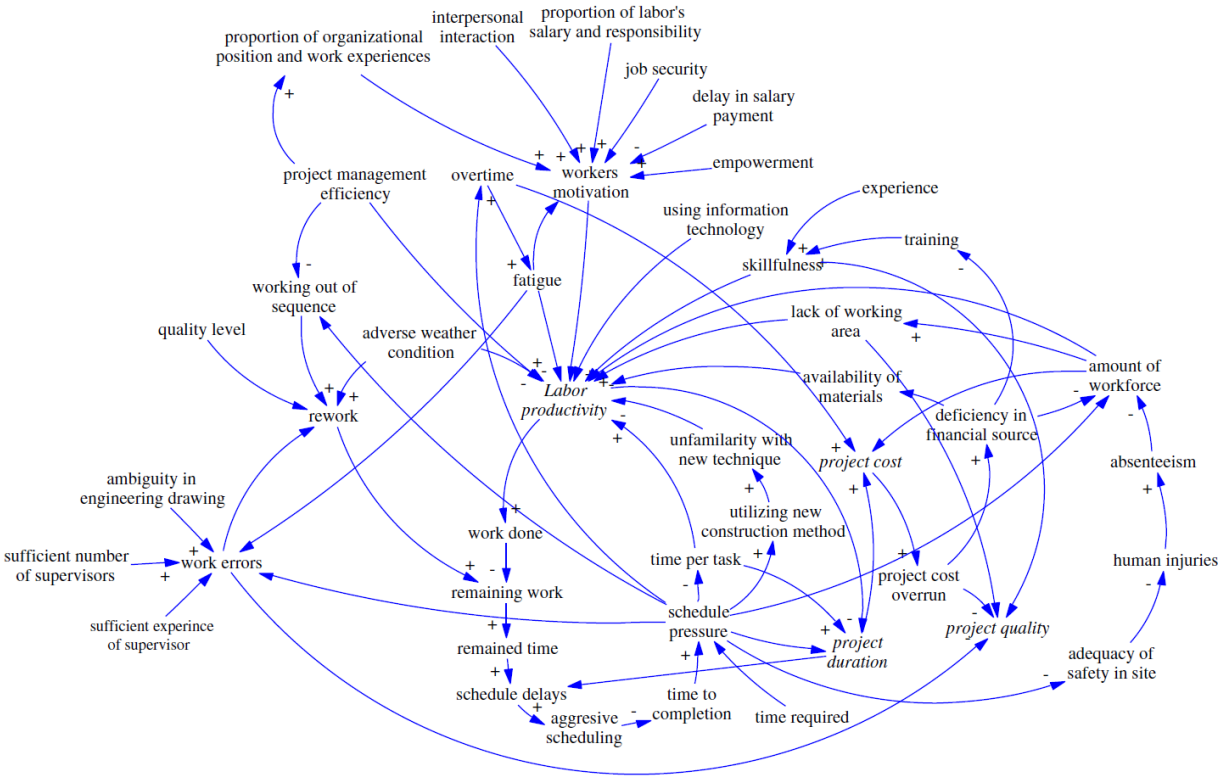

Figure 1:Conceptual model of labour productivity (Nasirzadeh & Nojedehi, 2012).

3 Characteristics of two NetZero renovations

This chapter discusses two cases of NetZero renovations. For both cases the authors discuss the characteristics, the labour productivity and the specific factors that affect labour productivity of the two cases.

3.1 Case 1: Tilburg

Figure 2: NetZero renovation in Tilburg, The Netherlands (Berben, 2015).

Characteristics

The first case is a NetZero renovation in Tilburg. Although the final product was very modern (NetZero), the process of the renovation was traditional. For instance the roof was made traditionally with purlins. The roofing sheets were lifted piece by piece to their final location. The work was very labour intensive. (Berben, 2015)

Figure 3: Roofing sheets were lifted piece by piece (Berben, 2015).

Labour Productivity

In a research Berben (2015) focused on the realization of the roof. He measured the labour hours needed for demolishing and mounting of the roof. In his calculation he excluded the (pre)fabrication hours of purlins, floors and roofing sheets. Berben estimates that wood work needs 0.17 hour per roof and roofing sheets needs 0.5 per m2 roof.

Table 1: Measured and estimated labour hours for the roofs of case 1 (Berben, 2015)

	Task	Traditional renovation	Measured or Estimated?
1a	Demolishing roof	7.5	Measured
2a	Mounting bearing structure	4.72	Measured
3	Mounting roof	13.63	Measured
4	Mounting gables	5.28	Measured
	Labour hours on site	31.13	Measured
	(Pre)fabrication hours wood work	0.17	Estimated
	(Pre)fabrication hours roofing sheets	33.0	Estimated
	Total	64.3	Estimated

The average labour hour per roof was 64.3. So the productivity for case 1 is:

$$Labour\ productivity = \frac{roofs}{labour\ hours} = \frac{1}{64.3} = 0.016$$

Equation 6

Factors that affect Labour Productivity

Berben used the stream analyses of Porras (Porras, 1987) to show the bottlenecks of the realization. The authors found the following factors that influence the labour productivity in case 1:

1. Adequacy of safety on site

2. Lack of working area
3. Complexity of design (A lot of dimensioning needed)
4. A lot of remaining work (a lot of small parts to be assembled on the building site)
5. Construction changes
6. Lack of skilfulness
7. Increasing time per task
8. Availability of materials
9. Schedule delays (sub-contractors are too late)
10. Work errors

3.2 Case 2: Soesterberg

Figure 4: Case 2 Soesterberg (Mulder, 2016).

Characteristics

In this case the providers renovated 81 houses in several phases form 2014 to 2015. The providers modernized the process by mounting conceptual prefab elements for roof and façade. But on the other hand the process was traditional because it was based on a fragmentation of tasks. The providers improved the process in every phase. Mulder (2016) (supervised and supported by one of the authors) researched the advantages of working in multi-disciplinary teams. She compared the interior finishing of phase 2 were the process was characterized by a fragmentation of tasks with phase 3 and 4 in which the provider took first steps in working with multi-disciplinary teams.

Figure 5: Process partly modernized (Sav, 2014).

Labour Productivity

Phase 2 was executed from October 2014 to January 2015. All the subcontractors had their own tasks and they completed the tasks for a fixed price. The contractors didn't monitor their labour hours. Mulder interviewed site managers and concluded that the renovations took 132 labour hours per house. But this hours were exclusive the unproductive hours as waiting, walking, pausing. Therefore it is impossible to calculate the labour productivity for the traditional phase 2. The only thing that can be concluded is:

$$Labour\ productivity\ (phase\ 2) = \frac{houses}{labour\ hours} < \frac{1}{132} = 0.00758\ (excl. prefabrication)$$

Equation 7

Factors that affect Labour Productivity

The providers didn't monitor the labour hours but monitored the execution time per house. The average execution time per house was 15.9. This was 10.9 days more than planned.

The causes for this delay were:

- Every party has to return several times to the same house
- Parties have to wait for each other when not finished a task
- Material is not always available
- A lot of personnel in one house
- A lot of exceptions on design (Mulder, 2016)

Translated to factors that influence labour productivity:

1. Increased time per task (returning and waiting)
2. Availability of materials
3. Lack of working area
4. Small repetition of design

4 Improving labour productivity

4.1 Case 1: Tilburg

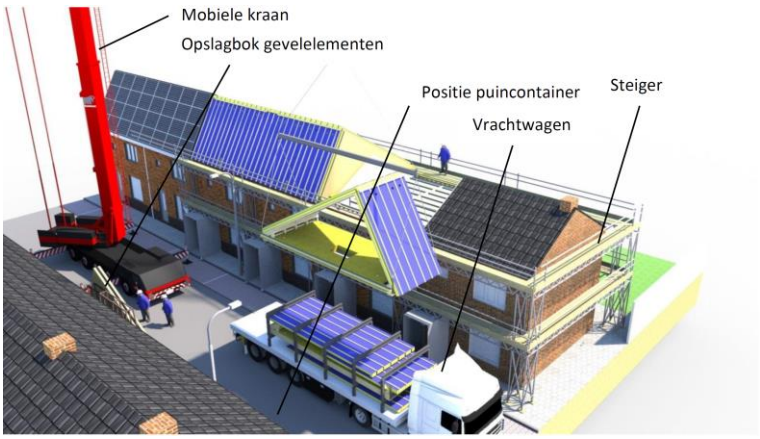

Figure 6:Fast retrofitting concept for roof of case 1.

Berben (2016) designed a fast retrofitting concept for building the roof of case 1. By prefabricating the roof he expect that it is possible to act on the bottlenecks as shown in **Error! Reference source not found.**. He calculated that mounting the roof in this way can save 10.92 labour hour on site per roof (Table 2).

Table 2: Comparing labour hours between traditional renovation of roof and fast retrofitting concept in Tilburg, The Netherlands (Berben, 2015)

	Task	Traditional renovation	Retrofitting roof concept
1a	Demolishing roof	7.5	7.5
1b	Preparation prefab roof	0	0.88
2a	Mounting bearing structure	4.72	2.58
2b	Adjustment for prefab roof	0	0.80
3	Mounting roof	13.63	3.26
4	Mounting gables	5.28	2.13
5a	Fitting sheet	0	1.68
5b	Waterproofing	0	1.38
	Labour hours on site	31.13	20.21
	(Pre)fabrication hours wood work	0.17	0
	(Pre)fabrication hours roofing sheets	1.0	0
	Prefabrication hours roof	33	16
	Total	64.30	36.21

Berben built a prototype. He estimates that the labour (pre)fabrication hours of the fast retrofitting concept of the roof are 40 when manually made and 16 when made industrial. The labour productivity of the roof can be calculated:

$$Labour\ productivity = \frac{roofs}{labour\ hours} = \frac{1}{36.21} = 0.028$$

Equation 8

4.2 Case 2: Soesterberg

To improve the renovation in Soesterberg the different providers tried to work in multidisciplinary teams. Those teams did most of the interior finishing with a high level of independency. In interviews the parties expected several advantages: (Mulder, 2016)

1. reduction of disturbance
2. increase of workers motivation
3. reduction of schedule pressure
4. increase of time per task
5. reduction of overtime
6. reduction of rework
7. increase of project quality
8. labour responsibility
9. reduction project cost and flow

Mulder expected the interior finishing of one house would decrease from 15.9 days (phase 2) to 5 days (phase 3 and 4). Now the providers monitored the time needed for renovating one house. The average execution time was 7.75 days (phase 3) and 10.5 days (phase 4). Although the average time of the renovation decreased, the decrease wasn't as expected. Mulder calculated the labour hours needed for assembling one house. She concluded that the teams worked 1032 hours while renovating 7 houses (phase 3) and 4648 hours while renovating 32 houses (phase 4).

$$Labour\ productivity\ (phase\ 3) = \frac{houses}{labour\ hour} = \frac{7}{1032} = 0.00680\ (excl. prefabrication)$$

Equation 9

$$Labour\ productivity\ (phase\ 4) = \frac{houses}{labour\ hour} = \frac{32}{4648} = 0.00688\ (excl. prefabrication)$$

Equation 10

Unfortunately the authors can't conclude if the labour productivity has been increased or decreased in phase 3 and 4 because the labour hours of phase 2 weren't monitored. But the authors found factors that influence labour productivity in interviews Mulder did after she saw an unexpected exceedance of the schedule:

1. Lack of appropriate communication
2. Lack of project management efficiency
3. Lack of experience in working in a multi-disciplinary team
4. Lack of training in working in a multi-disciplinary team
5. Lack of skilfulness in working in a multi-disciplinary team
6. Working out of sequence
7. A lot of work errors
8. A lot of rework
9. Wrong estimation of remaining work
10. Availability of materials
11. Lack of empowerment
12. Lack of labour's responsibility
13. Lack of workers motivation
14. Lack of amount of workforce
15. Lack of interpersonal interaction

5 Conclusion

In the table below the authors present the results of the analysis of two cases in one overview.

Table 3: Overview of results of the two cases

	Traditional renovation		Fast Retrofitting Concept		
Case	**Factors that affect labour productivity**	**Labour productivity**	**Concept**	**Factors that affect labour productivity**	**Labour productivity**
Case 1: Tilburg	Low adequacy of safety on site, Lack of working area, Complexity of design, A lot of remaining work, Construction changes, Lack of skilfulness Increasing time per task, Availability of materials, Schedule delays, Work errors	0.016 roofs per hour	Prefabrication of roofs	Adequacy of safety, Enough working area, Simple design, Little remaining work, Little construction changes, Skilful personnel, Appropriate planned time per task, No schedule delays, No work errors	0.028 roofs per hour
Case 2: Soester-berg	Increased time per task (returning and waiting), Availability of materials,	< 0.00758 houses per hour	Multi-disciplinary teams	Lack of appropriate communication, Lack of project management efficiency,	0.00688 houses per hour

	Lack of working area, Small repetition of design			Lack of experience in working in a multi-disciplinary team, Lack of training in working in a multi-disciplinary team, Lack of skilfulness in working in a multi-disciplinary team, Working out of sequence, A lot of work errors, A lot of rework, Wrong estimation of remaining work, Availability of materials, Lack of empowerment, Lack of labour's responsibility, Lack of workers motivation, Lack of amount of workforce, Lack of interpersonal interaction	

In the first case the labour productivity will increase spectacularly by prefabricating the roofs. This increase can be explained by the fact that the prefabrication will be in an industry hall were the climate and labour circumstances can be controlled. By prefabricating the roofs the builders influence the factors that affect the labour productivity. They influence factors such as the working area, simplicity of design and amount of construction changes.

Mulder monitored the realization of a fast retrofitting concept by multidisciplinary teams. In interviews all the providers expected several advantages, for instance increase of labour productivity. But because the traditional process hasn't been monitored, the authors can't conclude if the labour productivity will increase by working with multi-disciplinary teams.

There is no evidence that working in a multi-disciplinary team in fast retrofitting concepts can increase the labour productivity. But it would be unfair to conclude that working in a multi-disciplinary team will decrease the labour productivity. Working in multi-disciplinary teams is a new concept for the providers of Soesterberg. It is expectable that unexperienced contractors are in a learning curve. Further research has to point out if working in multi-disciplinary teams by experienced teams will increase the labour productivity.

As mentioned in the introduction not only the increase of productivity is of high importance. Also important is the time it takes to renovate on site because the customer keeps on living in the house during the renovation. The authors showed in the analyses that if the companies redesign their products and organize the processes in a sensible way the effect is a reduction of time on site and probably a better acceptance from the customer.

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