TOWARDS IMPROVING PRODUCTIVITY ON REFURBISHMENT PROJECTS

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Refurbishment projects have shown a negative productivity development in the last decades. In the REVALUE research project one aim was to work towards a productivity benchmark for refurbishment projects. Further, it evaluated the productivity potential inherent in the in the processes. A case study was used to collected data through a work sampling study, comprising to more than 2,200 data points. A lean perspective was adopted to estimate the share of time, a construction crew spends on value adding and non-value adding activities. The crew installs pre-fabricated lightweight facade modules, and the data analysis showed that 31% of the time was spent on direct work, and 69% of the time was spent on indirect work and waste. The analysis combined with observations on-site documented potential improvements. In total, it was possible to reduce waste with 12% and to increase productivity with 27%. The impact was a relative reduction between 8% and 21% in direct labour costs for the contractor, which equals a 1% reduction in client costs. Thus, the potential gain from increasing productivity are relatively higher for the contractor than for the client. The process showed an improvement potential, and a relatively large productivity increases.

Keywords: lean, productivity, refurbishment, waste

INTRODUCTION

Since the financial crisis in 2008, refurbishment have steadily increased its market share of the collected building activity. In 2017 refurbishment accounted for 35.8% of market in the the Danish construction sector, making it 42% bigger than new build construction, at 25.2%. In addition, the government's climate goals require Denmark to be CO2 neutral by 2050 (Danish Government, 2014). According to numbers from the Danish Government (2014) heating and running of equipment in Danish buildings account for 40% of the collected Danish energy consumption. Further it is estimated that most of the existing buildings today, will still be in use in 2050. Ravetz (2008) estimate that up to 75% of the present UK-building stock could be standing in 2050. Due to these circumstances, it is safe to assume that refurbishment will increase in the future, as the existing buildings must decrease their energy consumption to reach the ambitious climate goals. For the same reasons Kemmer and Koskela (2012) states "Refurbishment is one of the most important topics in the current research agenda in the UK", and that the research in the management of refurbishment projects is scarce.

Although very relevant, the productivity in refurbishment projects have been declining in the Danish construction sector since 1986, as the new build construction have shown a slightly increase (Tænketank for Bygningsrenovering, 2012). This productivity

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development results in less value and lower returns on investment in refurbishment. It also indicates that the prices increase faster than in other sectors. With rising demand for high quality refurbishment, the sector needs to find ways to reverse the negative productivity development. As the refurbishment sector grows, the need for more feasible and efficient solutions grows with it. This research will investigate the potential for improving productivity within the sector, by working towards a benchmark to hold future initiatives against.

Refurbishment

Refurbishment is more complex and uncertain than new build construction. The extent of the work is rarely completely known until the work commences, there is a higher need for specialized workers, less space and more risky work conditions, and the end-users are often present during construction. Further, refurbishment projects contain work which is unique to refurbishment and different from new build (CIRIA, 1994; Egbu, 1994; Egbu, *et al*., 1998).

Further the end-users of the refurbishment buildings are bound to be negatively influenced due to temporary nuisances like noise and dust (Holm and Bröchner, 2000). The process is therefore more valuable in refurbishment project as the contractors must work in suboptimal conditions to provide a service for the users (Sezer, 2014).

Kemmer and Koskela (2012) argues that lean theory is appropriate to handle the complex and uncertain nature inherent in refurbishment projects. Lean practiced on the Transformation-Flow-Value model, has shown superior project performance, especially in complex and uncertain conditions (Ibid.). Kemmer *et al*., (2013) valid this in 6 case studies, showcasing lean in refurbishment. Despite this, the practical application of lean practices to refurbishment projects, is still limited (Kemmer and Koskela 2012). That refurbishment is already substantial bigger than new build construction, makes it even stranger that it has received so little attention in the existing literature, at least in the execution stage of construction.

Productivity Measurements

Productivity can be calculated in different ways, but basically it describes the value of goods or services in a period of time of a production according to the usage of production factors. Productivity is difficult to measure because outputs and inputs are typically quite diverse and are themselves hard to measure.

Productivity can thus be difficult to compare across disciplines, and between different industries within the construction sector. This is due in part to difficulties in measuring inputs, and valuing outputs, especially in refurbishment projects, and because different professions have different production rates, and units of measurement, for example, concrete laid per hour (m3/hr) cannot readily be compared to other units or professions m2/hr finished surface.

The traditional measure of productivity can be very specific, and as Sezer (2014) argues as refurbishment is not pure production of goods, the physical measures of productivity such as concrete laid/m3, typical of new construction are insufficient. By itself it offers no suggestions as to how to improve the status quo, or information about the efficiency of the production. Instead another approach is chosen for this research, where the value generation is disregarded in the productivity measurements. The approach is called a work-sampling study (WS-study).

The advantage of a WS-study, is that it is relative regarding productivity. A work sampling study measures the time a worker spends on different activities, e.g. production, transport and waiting etc. A WS-study can thus be used as a crude estimate of the production efficiency (in this sense efficiency is understood as percentage of time spend on production, and on other activities). Two different professions, with different outputs, but roughly the same efficiency, will then have an equal relative productivity increase, if their productive time is increased in the same degree. WS-studies also provide clues to where improvements can be made to the process. These however, cannot be generalized, but used for optimization of each workplace.

METHOD

A modular construction project was chosen based on the following argument. The work is carried out at a single workstation making it comparatively simple to follow all craftsmen at the same time. The method is well established and it is possible to make a clear work description. Two other case studies on new build projects installing pre-fabricated modules on new build project are available for comparison of method and results (Nielsen and Kristensen, 2001; Dirchsen and Gantriis, 2015).

Case Description

The refurbishment case is a turnkey contract of DKK 320 million. It is a 3-year project from 2015-18, and is situated in Denmark. The refurbishment concerns 10 apartment buildings. It is primarily focused on making energy improvements through installing a new envelope and building service installations to improve indoor conditions. The project amounts to 23.700 m2 rented property floor area spread across 297 apartments.

The main renovations are to the following extent: basement windows are replaced, and the basement walls are insulated externally down to one meter below terrain. The entrance facades of the buildings are dismantled and new light pre-fabricated modules are mounted with windows attached. New insulated gable elements are fitted, and six gable windows are constructed in each apartment building. Rooflines are adjusted to the new wall thicknesses. All entrances are fitted with storm plackets. All apartments should be inhabitable during construction, but residents are in fact moved to temporary pavilions in near vicinity.

Work Description

The work performed in the study concerns the installation of light-weight pre-fabricated façade modules, from installation to finished surface. Prior to the installation, the building envelope is stripped to the naked concrete surface, and a new foundation for the self-carrying modules have been constructed. The installation process is as follows: Modules are delivered, released from restraints, and subsequently hoisted into place. The modules are mechanically fastened using metal bolts, drilled into the existing concrete slab. After all modules have been installed, all remaining gabs are insulated and sealed using wind plaster. The modules are then fitted with metal shins, and a surface layer of fibreboards. The installation process of 186 m2 from start to finished surface took approximately 4 days, for 3 workers full time, with a crane operator present 40% of the time.

Planning

The planning of the project is done using a mix of Location-Based Planning (LBP) and Last Planner System (LPS). The work is planned at a workshop with all sub-contractors present, and all the interdependencies between trades are found. There is no specific look-ahead schedule, instead LBP is used. Weekly work plans are not made in a traditional sense, as fast meetings with 20 people is unrealistic (according to Project Manager), instead the Foreman contacts each team individually to find out status, and if anything is missing. Percent Planned Completed (PPC) is not used, neither is any explicit restraint analysis or continuous learning mechanisms.

Data Collection and Validation

The data collected in the study is based on a work-sampling study. It is a quantitative visual collection method based on observations (Terp *et al*., 1987). WS-studies has been used for decades, and the key objective is to determine how time is being employed by the workforce, and in the 70'ies and 80'ies this was often wrongly refered to as productivity (Josephson and Björkman, 2013). Traditionally work would be divided into two categories, namely productive/value-adding and non-productive/wasteful. During the 90'ies especially Womack and Jones and Kaplan and Cooper promoted three categories, namely direct work, indirect work, and waste. As this tripartition seems to be grounded we apply this, but choose to sub divide indirect work into 3 categories (Conversation, Preparation, Transportation) and waste also into 3 categories (Walking, Gone, Waiting) in order to have better possibilities to analyse. These, in total, 7 categories were identified in advance and discussed with the workers, to ensure that they represented the performed work. The seven categories are presented below in table 1, with descriptions and examples.

Table 1 Definition of observation categories

Category	Descriptions and examples
Production/ Value- creation	Time used to work on modules or materials. Value is understood as a direct added value, but may also be in the form of adjusting a module; Processing materials, e.g. cutting facade panels; Crane yawing a module
Conversation	The time used to discuss drawings or work at hand. There is made no distinction between professional and private. Talking with crewmembers; Talking with resident; Talking on the cell phone; Talking with managers.
Preparation	Non-value adding handling of materials and elements, adjustments, and cleaning of machines and tools. Looking for tools or materials; Releasing module from truck; Measuring and marking; Hooking a module.
Transport	Workers carrying tools or materials from one place to another: Movement vertically in lifts between floors; Driving in a truck to retrieve materials; Crane yawing without a module.
Walking	Walking to and from locations without carrying any materials or tools. Walking between workstations; Walking to and from breaks.
Gone	Time away from the production site. Toilet visits; Other errands.
Waiting	The time spent waiting for colleagues, materials or information

In practice, we shadowed a construction crew of 4 workers (three construction workers and one crane operator) over six days. At random intervals between 1 and 7 minutes (15 observations per hour in average), we note the 4 works current activity into one of 7 categories. An activity cannot fall between categories; hence the observer will decide immediately which category. If one observation should fall into a wrong category creating uncertainty, this is dealt with statistically due to the high number of observations.

Measurement Uncertainties

There is a delay or deviation from the chosen observation time, to when the actual observations are made. Ideally, each observation should be made instantaneously, and the activity should be unambiguously categorized with the predetermined frequency. In reality this is not possible, as it is impossible to correctly categorize all workers simultaneously. (Terp *et al*., 1987). In addition, there are some uncertainties associated with the categorization of activities. Some activities fall in between categories, and others may be out of category.

The repetition effect is considered to have no influence on the workers' productivity. They are experienced and have installed pre-fabricated modules earlier. The results will show that they have developed a routine. Further, the observations take place half way through the overall installation period, with this being the 6th building out of 10.

RESULTS

Table 2 depicts the relative frequency of the categories from the WS-study along with the number of observations in each category. Note that Transport, Walking and Gone represent 33% of all time spend on site. The minimum and maximum values of the results, are based on statistical analysis of the 2221 observations. The maximum uncertainty is calculated at 2% and is confirmed by figure 2 that shows a steady distribution between the categories. Production (direct work) is therefore running 31% ±2% of the time, in the observation period.

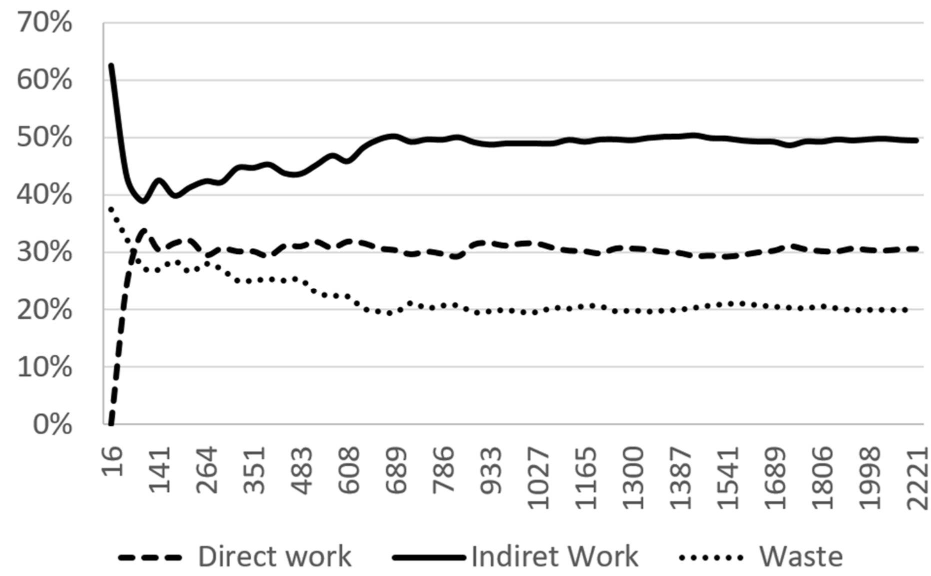

Figure 1: Relative frequency (RF) divided into categories.

Figure 1 shows how the relative frequency develops, as the number of observations increase in three categories: Direct work (production), Indirect work (Conversation, Preparation, Transportation), and Waste (Walking, Gone, Waiting). The relative frequencies settle around their respective averages, after 200 observations. The steadiness of the categories indicate that the team has experience and routine.

Comparable studies

The results are similar to two other Danish case studies, in which the productive time was measured on two new build projects installing pre-fabricated modules.

Table 2. Results from the case-study. The actual frequency of each category lies within the spans, with a 95.5% certainty.

Category:		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait
p_n	(%)	30.6	6.2	23.2	20.0	10.7	2.1	7.2
n		680	138	516	445	237	460	159

s	(%)	1.0	0.5	0.9	0.8	0.7	0.3	0.5
kn*s	(%)	2.0	1.0	1.8	1.7	1.3	0.6	1.1
p_min	(%)	28.7	5.2	21.4	18.3	9.4	1.5	6.1
p_max	(%)	32.	7.2	25.0	21.7	12.0	2.7	8.3

*Where: s=(p_n(100*p_n)/N)^0.5, for 95.5% certainty k_n=2, p_min,max=p_n±k_n*s Method from (Terp, 1987)*

Study 1 by Nielsen and Kristensen (2001) concluded that 29% of the time was direct work, based on 1,302 observations. Study 2 by Dirchsen and Gantriis (2015) found that 43% of the time was direct work, based on 1,138 observations. In a Swedish study (Björkman *et al*., 2010), focusing on efficiency of HVAC instalment on a mix of refurbishment and new build projects, the researchers found that 13.3% of the total work time was direct work. The results were based on 18,374 observations from 8 construction sites. Björkman *et al*., (2010) hypothesised that as construction moves towards modular construction, the share of time spend on actual production activities would decline, and the time spend on preparation and management would increase.

Production Rate and Lead-Time

To measure the actual relative productivity, the production rate of finished surface was calculated based on the progress of the construction workers. This is seen in table 3, and is based on four days' work for 3-4 people. Figure 1 shows the work distribution without breaks. The production rate without breaks are therefore the most compatible with the relative frequencies in table 2.

Table 3 Average production rate for the crew, with and without breaks

Production rate	Area		Man-hours		
Including breaks	178.6 m2	/	102.3	=	1.8m2/h
Excluding breaks	178.6 m2	/	86.7	=	2.1m2/h
Lead-time	Crane-hours		# Modules		
Unadjusted	19.58	/	52	=	22.58 min/module
Adjusted*	16.76	/	52	=	19.34 min/module

**Adjusted lead time is withdrawn breaks, and 10 minutes for setup/takedown of mobile crane, on four separate days with varying number of modules.*

The lead-time of a single module installation cycle was found by dividing the hours with a crane operator present, adjusted for breaks, and setup/takedown of the crane, with the number of installed modules. Again, the adjusted lead-time is more precise, as no data points was collected during breaks. The adjustment for setup/takedown was done, to consider a fluctuating number of modules being installed each day.

Data Trends and Observations

The individual categories were plotted throughout the day, to identify specific trends. The data was presented showing how the direct work production rate varied throughout the day. Based on data from five work days, and 1782 individual observations. The production rate was seen to be around 20% the first hour in the morning, after the first break, and again before closing time, relative to the average and peak production rates. Preparation (part of indirect work) was higher in the morning, steady between 20-30% in the afternoons, and then declined towards the end of the day. Movement (Transport, Walking and Gone) was high ~60% in the morning.

The following relevant wastes were observed during the observation period: Double handling of materials and tools, re-work, unnecessary movement, waiting.

DISCUSSION

Based on the observation it is possible to identify improvements, i.e. time savings, which will result in improved productivity. These are based on observations from site, and a discussion with the crew. The potential savings are measured in minutes per day per worker and presented in table 4.

Table 4: Potential time savings to increase productivity

9 minutes	Increasing production-rate the first hour, from 20% to 35% would result in 9 minutes increased production each day. The crew suggested that toolboxes permanently on the lift would reduce the time spend on getting the workstations ready. Other improvements could be found using 5S or creating "best practices" and improving routines through continuous learning.
14 minutes	Reducing lead time on the module installation by two minutes per module, ~10%, would on average could save 14 minutes per worker per day in the observation period. The crew suggested a smarter interlock system between modules. The authors suggest using VSM to locate and eliminate waste by improving the process.
12 minutes	Reducing movement categories by 10%, from 31% to 28%, would save 12 minutes per day. It is suggested to introduce routines and Kanban to reduce the number of forgotten tools, and improved communication between trades.

The suggestions were not implemented, as it was not in the scope of this research to identify barriers to these implementations.

Impact

A workday consisted of 7 hours a day equal to 420 minutes. According to the frequencies calculated in table 3, this provides 130 minutes of production, and 290 minutes of waste each day. Reducing waste by 35 minutes per day, equals a 12% relative reduction of the waste category. The relative increase in productive time is however, equal to 27%.

Calculating the impact of these changes on an economic scale can be done in, at least, two ways. If the productivity is increased, as a result of increased direct work time, the output is increased by 27%, and the project is finished 21% earlier, thus saving 21% on labour costs. If the workers finish early, and does not capitalize on the time saved from waste reduction, the contractor saves 8% on labour costs. Economic impact for the GC is based on instalment of 185 m2 façade, with actual wages of £ 8,205.

Representativeness

A work sampling study does not show the productivity, but it shows the efficiency of a process with a given output. Because all workers have their own pace, it is not possible to measure the output of one worker based solely on his work sampling results. It is assumed that the workers will increase their hourly average production rate, calculated in table 3, as their hourly productive time increases in the ratio of 1:1. This is based on the observation that, all value creation is occurring in the measured productive periods, and none is happening in any other category. Thus, increasing the productive time, should increase the output accordingly.

The crew spends 31% percent of the time on value adding activities and 69% of the time on non-value adding activities from a Lean perspective. A change in this distribution creates relatively large productive gains. By reducing the wasteful activities 35 minutes per day, it is possible to achieve an increase in efficiency of 27%. This effect works both ways and illustrates the importance of continuously shielding production from interruptions. Every time a piece of equipment is missing, and workers stops for 5 minutes, it equals four percent of daily productive time. If a work stops for 30 minutes, because of a delay in materials, it equals 23% of the daily productive time. The 30 minutes of stop is an example of why flow management and shielding activities by the planners is so important, and the 5 minutes stop is an example of deficient organization of the work at the workstation. This underlines the importance of efficient flow management and shielding activities using Last Planner System and/or Location-Based Planning, and illustrates how variation in flow and "small" delays have a relatively large negative impact on the productive time. In turn, proper organization of the work, with routines and "best practices" and will have the opposite - positive - effect on productive time and productivity. In the present case, several Lean tools are hypothesised to have a positive effect on reducing waste from table 1. These are mentioned here, but the underlying theory is not elaborated, and are based on observations from site: 5S, Kanban, Value Stream Mapping.

Some issues come to mind when generalizing based on results from 3-4 people. Does the 31% productive time represent every construction worker? Probably not. But it can be used as a rough estimate to calculate the effect or impact of delays or time savings made at the construction site. It puts delays into perspective, when compared to missed opportunity for progress, and it makes it possible to value small improvements, that could otherwise be forgotten. The results are in the middle, compared to the three other studies, but relatively higher than the larger study from Sweden showing 13.3%. The results are, therefore, considered rather conservative, but probably varies between professions. If the general productive time has a tendency to be lower, towards the Swedish study, the impact of improvements and delays would become more exaggerated, and the contractors would benefit even more from making improvements to their current practice. If the results in the present study are pessimistic, and the average workers time distribution has more productive time, suggested improvements would merely result in smaller productivity improvement, however still relevant, as it equals savings for the contactors expenses.

Does Work Sampling Studies Measure Productivity

Work sampling studies does not measure productivity per say. It rather values the efficiency of production, by observing only if production is running or not. It is not possible to determine the output of a process based only on the results from a WS-study. Two workers can have the same distribution in the observation categories, and entirely different outputs. The production rate, i.e. actual productivity is not measured in a WS-study, and varies between the individual workers and different activities. It is however hypothesized, that each worker has an individual production rate in every activity, and increasing the time spend on actual production, will increase his output according to this rate. If production methods change, increasing the production rate enormously, the share of productive time would likely decrease, as logistics at a building site rarely allows a big supply of recourses at the location of installation.

CONCLUSION

As refurbishment takes up increasing market shares, the focus is on higher productivity in the sector to create more value at less costs. Despite this, the productivity development in the construction sector as a whole, and in refurbishment in particular, is low. Refurbishment projects are more complex and uncertain than new build. Research is needed to document positive effects on productiveness in refurbishment projects. As productivity can be difficult to measure and transfer from one case to another, this paper has conducted a relative measurement of productive time on a refurbishment project through a work-sampling study.

A benchmark of productivity on a refurbishment project have been presented in the form of a relative measurement of the time workers spend each day. On average, a worker spends 31±2% of his daily time on production equal to 130 minutes daily. The rest is spent on activities that do not create value for the client. By reducing time spend on non-value adding activities, the impact on the daily productivity was calculated. In the present case, hypothetical time savings were collected. It was shown that decreasing waste by 12% per day per worker, increase efficiency by 27%. This would in in turn reduce the contractor's direct labour costs by 8-21%, depending on the calculation method. The results from this study, can be used to calculate relative productivity increases gained from waste reducing initiatives. The study has shown, the consequences of relatively small amounts of time waste on daily productive time. Five minutes of waste due to bad organisation at the workstation is equal to 4% reduction in daily productive time, and 30 minutes of delay due to bad planning, is equal to 23% reduction in productive time for the workers. It is hoped that this study can help increase the focus on waste and insufficient planning, by showing the relative impacts on production.

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REFERENCES

Björkman, L, Josephson, P and Kling, R (2010) *Arbetstidens Användning Vid VVS-Montage - En Fråga Om Struktur Och Ledarskap*. Göteborg: VVS-företagen.

CIRIA (1994) *A Guide to the Management of Building Refurbishment, Report 133*. London: Construction Industry Research and Information Association.

Danish Government (2014) *Strategy for Energy Renovations of Buildings*. Copenhagen: The Ministry of Climate, Energy and Building.

Dirchsen, T N and Gantriis, K F (2015) *Tidsstudier af Montagearbejde i et Leanperspektiv*. København, DTU.

Egbu, C O (1994) Management education and training for refurbishment work within the construction industry. Salford, UK: Department of Civil Engineering and Construction, Salford University.

Egbu, C O, Young, B A and Torrance V B (1998) Planning and control processes and techniques for refurbishment management. *Construction Management and Economics*, **16**(3), 315-325.

Holm, M G and Bröchner, J (2000) Office conversions: The effects of craftsman-user interaction. *Facilities*, **18**(13/14), 535-545.

Josephson, P and Björkman, L (2013) Why do work sampling studies in construction? The case of plumbing work in Scandinavia. *Engineering, Construction and Architectural Management*, **20**(6), 589-603.

Kemmer, S, and Koskela L (2012) Developing a Lean Model for Production Management of Refurbishment Projects. *In*: *20th Annual Conference of the International Group for Lean Construction (IGLC 20)*, 18th-20th July, San Diego, USA, 44-54.

Kemmer, S, Koskela, L and Nykänen, V (2013) *Towards a Lean Model for Production Management of Refurbishment Projects*. VTT Technology, 94.

Nielsen, A C S and Kristensen, E L (2002) *Plan Byg - Effektivisering af Byggeprocessen Visualiseret Ved Spillet Plan Byg*. Aalborg, AAU.

Ravetz, J (2008) State of the stock - What do we know about existing buildings. *Energy Policy (Energy Policy)*, **36**(12), 4462-4470.

Sezer, A A (2014) Indicators of environmental and productivity performance for building refurbishment projects. *In*: Smith, S D and Ahiaga-Dagbui, D D (Eds.), *Proceedings of the 29th Annual ARCOM Conference*, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 949-957.

Terp, B E, Christiansen, N M, and Lindegaard, I M (1987) Metode Styring 3rd Edition. Odense: Erhvervsskolernes Forlag.

Tænketank for Bygningsrenovering (2012) *Fokus på Bygningsrenovering*. Grundejernes investeringsfond og Realdania, in Danish.