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PRODUCTIVITY MEASURES, FACTORS AND RESULTS IN CONSTRUCTION:

A BRIEF LITERATURE REVIEW

Stefan Christoffer Gottlieb & Christian Koch

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Contents

1. INTRODUCTION

This brief literature review will present experiences from international studies, publications and databases on the topic of productivity in construction. It should not be seen as a comprehensive review, and it will not attempt to correlate findings from various studies by recalculating results to take into account that different studies have employed different methods.

The review is made in response to the SBUF funded projects on Produktivitetsläget i svenskt byggande 2014 and Produktivitetsläget i svenskt byggande, VVS och el 2018 conducted by Chalmers University of Technology and reported by Koch and Lundholm (2018).

The report is structured into four main chapters. In chapter 2, we will briefly contextualize the study by presenting the Swedish study "Produktivitetsläget i svenskt byggande" by Koch and Lundholm (2018) that serves as the starting point for the analysis.

In chapter 3, we will explain our methodical basis and how we have analyzed the data from the identified literature.

Chapter 4 is the main result section, where we present the various studies and their results. This is structured in country specific sections, where selected studies/initiatives to measure productivity is presented. For each study, we elicit the type of study; the actors involved, and then briefly highlight and comment on the data collection and calculation methodologies in each case.

This will be followed by a crosscutting analysis and summary in Chapter 5. Here we discuss differences and similarities between the various initiatives to establish whether there is support for the Swedish results, and how these relate to international experiences. We will also summarize the factors influencing productivity across the different studies, and comment on the general findings.

The appendices contain a schematic overview of the studies and the findings.

2. PRODUKTIVITETSLÄGET I SVENSKT BYGGANDE

Koch and Lundholm (2018) have completed a productivity analysis of the Swedish construction industry entitled Produktivitetsläget i svenskt byggande. The overall aim of the study is to contribute to productivity development in construction projects, construction companies, plumbing companies and electrical installers by developing knowledge about productivity conditions, challenges and areas of strength. This project has been carried out as a productivity measurement of Swedish construction, plumbing and electricity 2018. This means an overall streamlined data collection, with opportunities for cross-sectional analyzes across the different areas.

The project is based on a questionnaire survey encompassing the 430 of the largest construction projects completed and completed in 2018. The survey includes the construction of: remises, offices, apartment buildings, group-built detached houses and construction projects. For installation and electricity, focus is also on their assignments within the largest construction projects.

The project has worked with a model for productivity that measures productivity in terms of costs per produced square meter. When determining project productivity focus is on measuring the cost of construction, including transport, wages, materials, machinery, groundworks, subcontractors, installations, etc., per gross square meter. All data were reported by clients and site managers based on a distributed survey. The following costs were found:

Figure 1: Costs per square meter (Koch and Lundholm, 2018)

Percentil	Byggkostnad (kr/m² BTA)
10-percentil	8 143
25-percentil	12 500
50-percentil (medianvärde)	18 833
75-percentil	25 000
90-percentil	31 243

In the report, the cost figures were moreover broken down according to building typologies, clients, regions, project size, etc. Moreover, project duration, person-hours, delays and causes of delays, contracting form, etc. were recorded and analyzed.

The project focused specifically on understanding factors influencing productivity at a project level, and in particular so-called “störningar” or disturbances that impact construction costs as illustrated in the model below.

Figure 2. Foundational model for measuring productivity (Koch and Lundholm, 2018: 12)

The report identified a number of productivity influencing factors, including collaboration model, geographical location, weather and logistics. On this basis, the following report constitutes a review of international studies of productivity influencing factor, to identify other factors that might explain variances and results from Koch and Lundholm's (2018) study, and be used as a basis for future productivity analyses in the Swedish construction industry.

3. METHODS AND APPROACH

This study has been conducted as a systematic literature review (Kitchenham, 2004). The aim has been to collect information on productivity analyses, measures, factors, and results as they have been reported in industry and academic studies and reports. As our interest has been in specific studies that have produced or reported on primary data on productivity that are comparable to the Swedish study by Koch and Lundholm (2018), we focused on technical reports financed by research councils, industry or government agencies and used academic papers as secondary sources.

Literature review

In order to identify technical reports and government/industry initiatives reporting productivity data, we started by identifying relevant boards, councils, agencies, etc. in different countries, which we were acquainted with from previous professional work. In addition, we searched institutional repositories at research institutions and universities, which we knew had done work within this area. This initial search yielded a (non-exhaustive) list, which is included in Appendix 1: Studies and sources. These studies treated productivity rather differently, ranging from reporting labor productivity based on data from various national statistics' bureaus to KPIs used in benchmarking schemes. Other studies had a much more detailed focus on construction costs and analyses of factors influencing productivity.

To supplement these, potentially biased, studies we also conducted a review of the academic literature. We searched for documents in several databases, including Scopus and Google Scholar as the primary databases. Google Scholar was used in the first round of relatively unstructured search, which focused on identifying articles that reported productivity data in the housing construction sector. This led to the identification of a few selected papers that were used as point of departure for a search by snowballing, i.e. following both references and citations, which yielded more papers and keywords, which were used in the subsequent structured Scopus search.

The purpose of the Scopus search was to find studies that had a relationship to the previously identified industry/government initiatives, and who either confirmed or refuted any results or findings proposed herein. Moreover, we had an interest in supplementing the technical reports' finding on factors influencing productivity. This was however a rather futile process, as the majority of papers referencing the industry/government initiatives did so in an introductory/political setting instead of focusing on the results. Moreover, the majority of papers reporting on factors influencing productivity did not contain any primary productivity data, but was based on generic questionnaire input from industry stakeholders.

An additional issue with several of the papers that were identified was that they dealt with productivity in developing countries or in countries in the Asian and African regions. While such papers conform to academic standards and the quality of the finding should not be questioned for this reason, the focus on different national and cultural settings might compromise the relevance of the finding in a Swedish context, as several issues e.g. a developing country might struggle with, are not comparable or relevant in Sweden. Several papers e.g. focused on the impact of corruption or late payment on productivity, which might be considered less relevant or influential in a Nordic context.

Data analysis

After compiling the different reports and papers, we read the entire documents focusing on the results' sections and the methodologies employed. We structured the information provided into the following categories (where applicable):

- Name of initiative/report
- Country of origin
- Productivity definition employed
- Level of analysis
- Type of study
- Methodologies employed
- Input data
- Output measure for productivity
- Main findings
- Factor influencing productivity
- Additional data presented
- Miscellaneous notes about the study

In relation to the issue of factors influencing productivity, we took all data and coded it according to the flowing categories:

- Metrics (input variables)
- Meta-descriptors of the metrics
- Factors influencing productivity
- Meta-descriptors of the factors
- Proposed correlation between factors and productivity improvements

This work was conducted in order to reduce the number of individual metrics and factors by working with aggregated, or second-order, constructs and examine any relationships between these and potential productivity improvements.

As an illustration, we identified 62 different metrics in the studies that we reduced to 16 meta-descriptors of metrics. Likewise, 116 identified factors influencing productivity were grouped into 16 different meta-factors. The following figure illustrates this principle:

Figure 3: Example of coding of identified metrics and factors according to meta-descriptors

Meta-descriptor	Metrics or factors employed in the identified studies
Time	- Lead time - Predictability Time - Project - Predictability Time - Design - Predictability Time – Construction - Time consumption - Days elapsed on site - Man hours on site - Days on site/m2
Technology	- Prefabrication - Digitalization - Building materials - ICT - Industrialization - Use of offshore (remote) engineering - External services

In the crosscutting analysis, se discuss the findings according to these aggregated dimensions. We refer to Appendix 2: Coding of data for a full list of metrics, factor and meta-descriptors.

We refer to Appendix 3: Raw data from the literature review for an overview of the elements identified in the literature review.

4. INTERNATIONAL RESULTS AND EXPERIENCES

In this chapter, we will present the international results and experiences drawn from various sources. Some of the findings reported are based on scientific studies, whereas others are industry databases, and some again governmental reports. We do not discuss the validity of the data reported by the various sources.

Danish experiences

In Denmark, systematic investigations of project level productivity have not been carried out in the extent of the Swedish study. Several one-off productivity measurements have been conducted, but these have mainly focused on on-site labor productivity and observed operational time consumption without relating these to output value in terms of costs etc.

Byggeriets Evaluerings Center

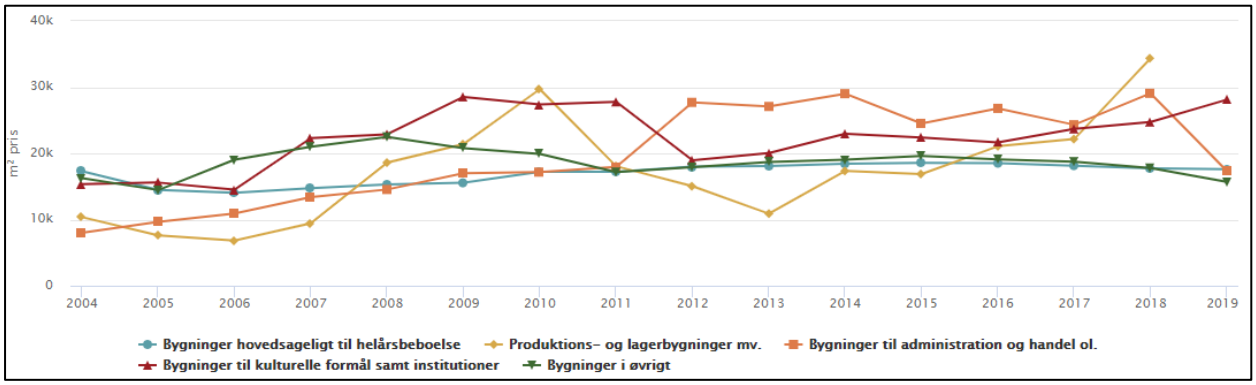
In Denmark, numerous government initiatives have been carried out over the years in an effort to improve the industry's productivity. In 2000 the so-called Task Force Report was released. The report paved the way form the establishment of a Benchmark Centre for the Construction Industry.

Byggeriets Evaluerings Center (The Benchmark Centre for the Construction Industry) has collected data from completed projects since 2004 as a part of a mandatory benchmarking scheme for public and publicly subsidized buildings. In 2016, the mandatory benchmarking scheme was abolished and the benchmark center continued operations in a voluntary setup. This means the data making up the database is discontinuous, as different types of companies have been benchmarked.

Data is reported on projects concerning time, cost, satisfaction etc. The below figure reports the cost per square meter for different building typologies reported by the clients.

Figure 4: Statistics – square meter prices

(https://byggerating.dk/database/kvadratmeterpriser)



The buildings cover schools, daycare institutions, offices but also dwellings. Zooming in on the numbers in 2014 and 2018 shows the following figures:

Figure 5: Statistics – square meter prices

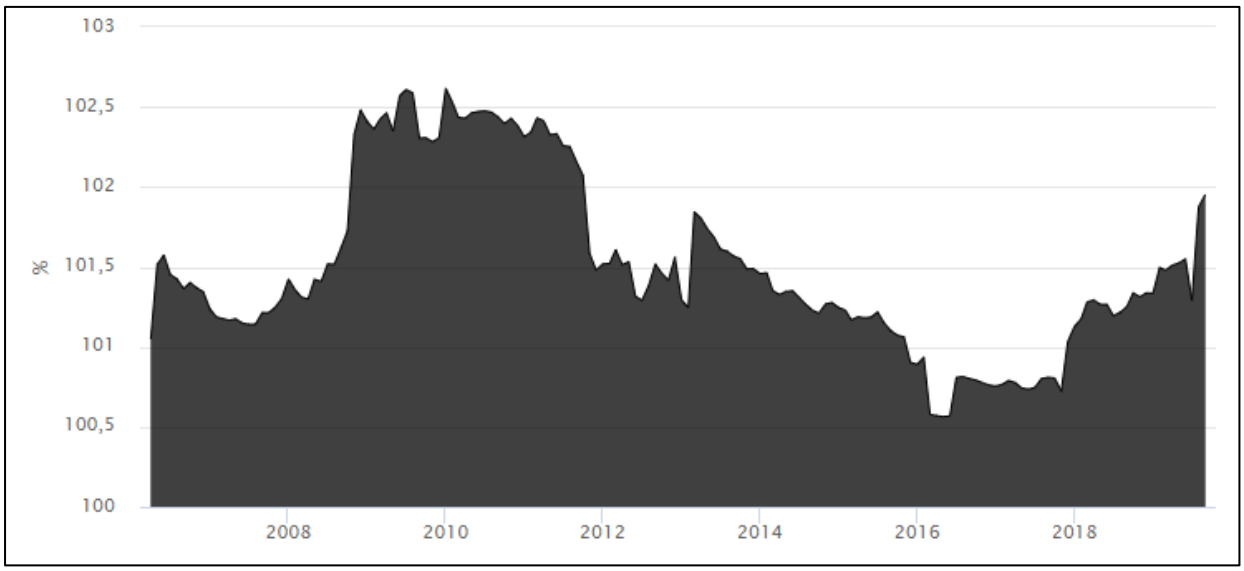
(https://byggerating.dk/database/kvadratmeterpriser)

Building type	2014 square meter cost DKK (no. projects)	2016 square meter cost DKK (no. projects)
Permanent residence	18.431 (330)	17.742 (77)
Production and storage	17.332 (2)	34.361 (1)
Administration	29.016 (13)	29.072 (7)
Cultural and institutions	22.940 (48)	24.7635 (32)
Other	19.022 (27)	17.784 (17)

All costs are calculated in fixed prices using appropriate indices for discounting. In addition to cost data, the benchmark center also collects information on lead-times including differences between planned and realized lead-time. An example is provide below:

Figure 6: Actual/planned lead-time

(https://byggerating.dk/database/statistik-entreprenoerer)



UK experiences

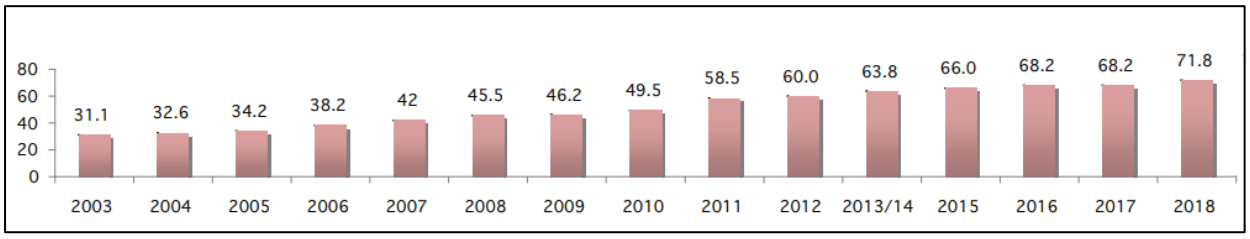
The UK has had many different initiatives aimed at improving and measuring productivity in the industry. Most notably, the Constructing Excellence (CE) platform, which was established in 2003, when a group of public and private organizations merged, has played an important role. CE has driven the development of KPIs and benchmarking in UK. CE measures how assets are designed, constructed and managed to benchmark performance and drive improvement.

Constructing Excellence

Each year, CE publishes construction industry KPIs using performance data collected from across the UK construction sector by Glenigan with support from the Department for Business, Innovation and Skills. KPIs include economic indicators as well as satisfaction ratings to mention but a few. Economic indicators are compiled from projects

completed in the preceding year. Economic KPIs include a wide range of indicators ranging from client satisfaction over cost and time predictability to productivity measures. Productivity is measured in value added per employee, as the below illustration shows:

Figure 7: Value Added Per Employee (VAPE) (Constructing Excellence, 2018: 20).



For 2014 and 2018 the following figures are reported:

Figure 8: Value Added Per Employee (VAPE) (Constructing Excellence, 2018: 20).

	2014 (£000)	2018 (£000)	Change
Productivity (VAPE Current Values)	63,8	71,8	12,5 %
Productivity (VAPE Constant 2016 Values)	64,2	70,3	9,5 %

In contrast to the Danish and Swedish figures, data is recorded on an industry level and not on a project level.

Construction Leadership Council

The Construction Leadership Council (2018) is in the process of establishing a system, which enables the collection and management of key metrics to track progress for the Innovation in Buildings workstream. The system is an industry level benchmark system consisting of 13 KPIs. For each KPIs a review of information currently available has been carried out to produce a current benchmark figure as well as a target for 2020. The benchmark is built on a variety of different sources including RICS, BRE, NHBC, ONS and miscellaneous government data. Metrics include waste, BIM usage, safety and quality, but also cost data.

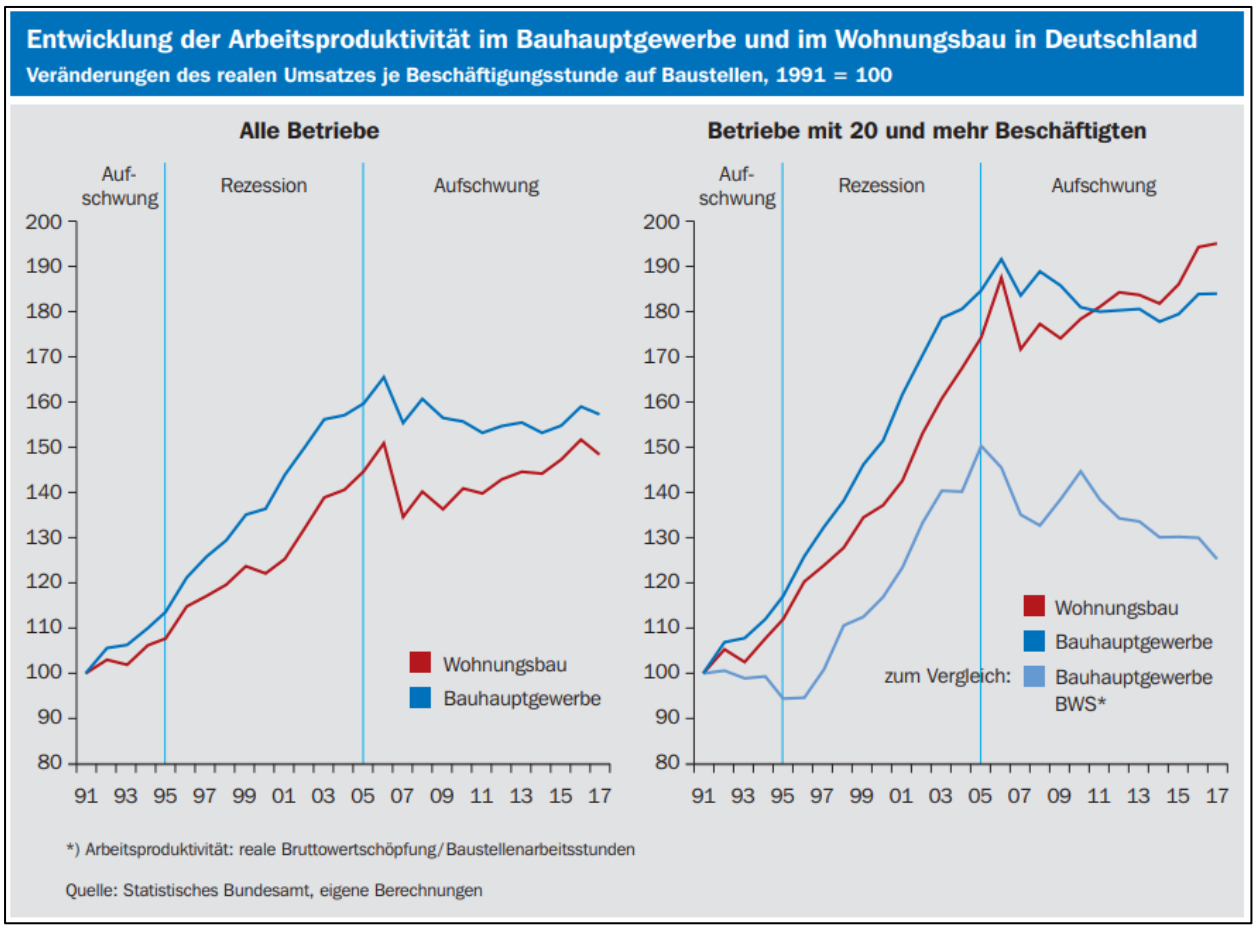
German experiences

German experiences are collected from professional associations.

Die deutsche Bauindustrie

Die deutsche Bauindustrie is a German association representing more than 2000 large and medium sized companies in the construction industry. In the paper on the "Kapazitätssituation im deutschen Bauhauptgewerbe" (Die deutsche Bauindustrie, 2018) they have studied the development of labor productivity in different segments of the industry. Figures are provided in relative numbers according to a 1991 index.

Figure 9: evelopment of labour productivity (Die deutsche Bauindustrie, 2018: 19).



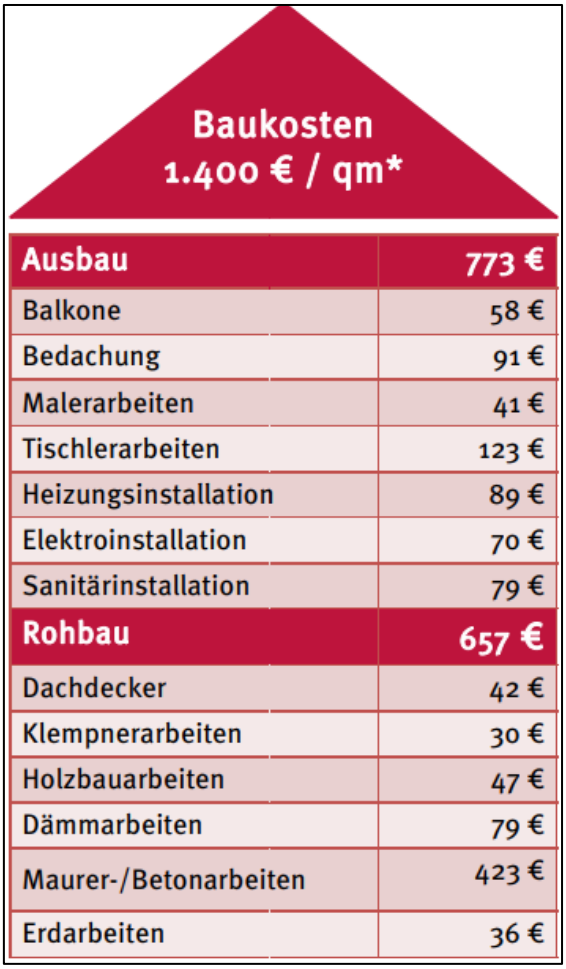
This labour productivity index is calculated at an industrial level.

Bundesvereinigugn Bauwirtschaft

Bundesvereinigugn Bauwirtschaft is the Federal Construction Industry Association, which represents the common cross-trade interests of the German construction companies. On their website, they have provided a calculation of the square meter cost of a 12-unit apartment building. The calculation is based on a report by Walberg et al. (2014). The cost of construction is calculated at EUR 1.400 per square meter with the following distribution on costs for building envelope and interior works:

Figure 10: ost distribution of multistory apartment

(http://www.bv-bauwirtschaft.de/zdb-cms.nsf/res/BaukostenI.pdf/$file/BaukostenI.pdf)



Ausbau	**773 €**
Balkone	58 €
Bedachung	91 €
Malerarbeiten	41 €
Tischlerarbeiten	123 €
Heizungsinstallation	89 €
Elektroinstallation	70 €
Sanitärinstallation	79 €
Rohbau	**657 €**
Dachdecker	42 €
Klempnerarbeiten	30 €
Holzbauarbeiten	47 €
Dämmarbeiten	79 €
Maurer-/Betonarbeiten	423 €
Erdarbeiten	36 €

In addition, costs related to logistics, ground works, elevators, underground parking, basement, and additional building expenses amount to app. EUR 1.000 per square meter.

Norwegian experiences

In Norway, there has been many initiatives investigating the productivity and efficiency of construction activities.

Byggkostnadsprogrammet

Byggkostnadsprogrammet (2010) was a Norwegian governmetal R&D program to reduce house prices, construction costs and increasing the productivity in the industry. In 2003, a working group was set up to assess measures and a form of collaboration to reduce the growth in construction costs and increase the efficiency of the industry. A five-year program aimed at the building, construction and real estate industry was initiated and in 2010, the final report was released summarizing the finding form the program. The report concluded on factors influencing productivity, including quality assurance, ICT, industrialization, lean methods, collaboration and the role of regulation.

Effektivitet og produktivitet i bygging av veier i Norge 2007-2016

Rødseth et al. (2019) have conducted a study on the development of efficiency and productivity in road construction, and analyzes 137 road projects that were completed in the period from 2007 to 2016. The study is a dual study of the industry's productivity development based on the national accounts, and a micro study focusing on productivity and efficiency analysis of road construction.

The main findings from the study are that:

- the productivity development of road construction projects has been weak
- small projects are more productive and cost effective than large projects
- there are differences in productivity between regions, however the region that exhibits the highest cost level but also undertakes the largest projects
- conditions such as topography, ground conditions, and population density affect the costs

In the report, Rødseth et al. (2019) review different ways of measuring productivity in construction, and look into existing studies of drivers of labour productivity based on extent research. These will be presented later in the review.

Produktivitet i bygg- og anleggsnæringen

In 2001-2006 SINTEF completed the project "Produktivitet i bygg- og anleggsnæringen" that aimed at developing a methods for calculating efficiency and find best practice in Norwegian construction. In the project 122 relatively similar housing projects was measured and benchmarked. The results were published by Ingvaldsen and Edvardsen (2007).

A total of 407 parameters have been collected and tested for correlations with projects productivity and efficiency. Fourteen of these parameters were found to have a statistical significant relationship with productivity. Eight of the fourteen parameters were related to managerial priorities, and the remaining six were related to project framework conditions.

The six covariant framework factors are (number refer to parameter code):

- Site layout (D-42)
- Environmental demands (D-69)
- Use of bonus agreements (D-52)
- Type of purchasing agreement (D-62)
- Company size (A20-A23)
- Ratio of salaried to hourly paid wage costs

The findings were that:

- Crowded / hard accessible sites were less efficient than other sites

- Projects conducted according to the "Rent bygg dagli-regime" (an environmental production regime) were led efficient than projects without same demands
- Project with a bonus agreement for salaried employees were more efficient than those without
- Coordinated (centralized) purchasing agreements lead to increased efficiency
- Projects completed by large companies have a lower efficiency than smaller companies
- Projects with a high ration of salaried to hourly paid worker have a lower efficiency

The eight parameters related to managerial priorities are (number refer to parameter code):

- Rework costs (D67)
- Sanctions imposed by work environment authorities (D-65)
- Personal injuries (C-52)
- Financial follow-ups (E20-7)
- Delays (E30-19)
- Overtime work (E-30-38)
- Bilateral discussions with (trade union) representatives (E-30-30)
- Purchases form specialists (E-30-25)

The findings were that

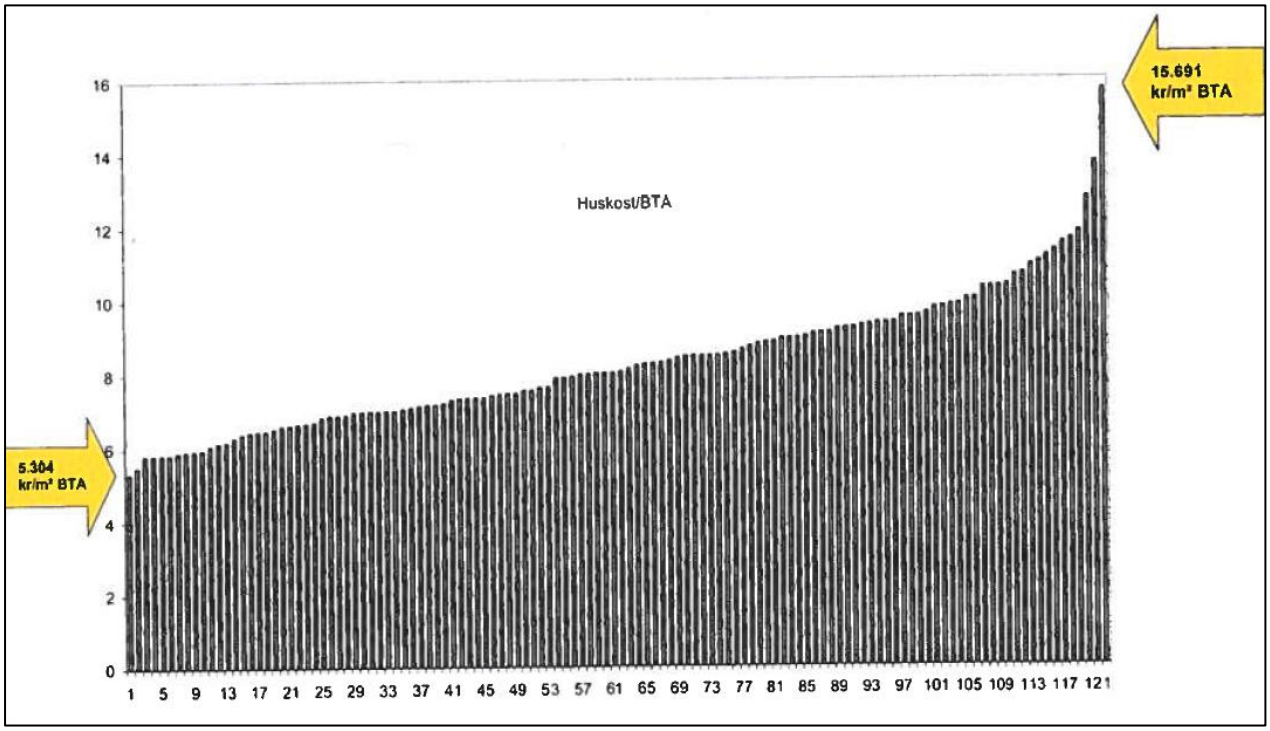
- High rework costs correlates with low efficiency
- Sanctions imposed by work environment authorities correlates with high efficiency
- A high number of personal injuries correlates with low productivity
- In projects with high efficiency project managers often:
    - used much time on economic follow-ups
    - deemed it prestigious to make up for delays as soon as possible
    - were reluctant to ask people to work overtime
- In projects with high efficiency project managers rarely:
    - had bilateral meetings and discussions with (trade union) representatives about mitigating negative effects of absenteeism
    - bought services from internal or external specialists

The findings from the project in terms of costs per square meter were:

- Minimum NOK 5304
- Maximum NOK 15691
- Mean value NOK 8271

The cost per square meter distribution for the 122 projects is illustrated below.

Figure 11: Cost per square meter in 122 projects (Ingvaldsen and Edvardsen, 2007: 50)



The data in this report is probably the international data that comes the closest to the data reported in the Swedish study by Koch and Lundholm (2018).

International (meta-)reviews

The international meta-reviews present factors drawn and compiled from multiple existing studies. We have identified several studies by the same authors where it seems that the same dataset, i.e. results from the meta-review has been used. In these cases, we have only included one of the studies.

Kazaz and Acıkara (2015)

Kazaz and Acıkara (2015) have produced a comparison of labor productivity perspectives of project managers and craft workers in the Turkish construction industry. As a part of the study, they have conducted a literature review of factors influencing productivity. They have grouped factors into economic, organizational and socio-psychological factors. The significant factor identified are reproduced in the figure below.

Figure 12: Significant factors influencing labour productivity in construction (Kazaz and Acıkara, 2015:495)

Craft workers' perspective			Managers' perspective		
Rank	Name of Productivity Factor	Factor Group	Rank	Name of Productivity Factor	Factor Group
1	Working in social insurance	Economic	1	Quality of site management	Organizational
2	On-time payment	Economic	2	Material management	Organizational
3	Amount of pay	Economic	3	On-time payment	Economic
4	Dining hall-and-dorm conditions	Organizational	4	Systematic flow of work	Organizational
5	Health-and-safety conditions	Socio-psychological	5	Supervision	Organizational
6	Quality of site management	Organizational	6	Site layout	Organizational
7	Systematic flow of work	Organizational	7	Work discipline	Socio-psychological
8	Work discipline	Socio-psychological	8	-	-
9	Relaxation allowances	Organizational	9	-	-

Hughes and Thorpe (2014)

Hughes and Thorpe (2014) have conducted a study to ascertain the perception, from the project manager's viewpoint, of factors affecting construction productivity in the State of Queensland, Australia. Based on a structured questionnaire that was sent to 89 randomly selected construction project managers, they investigate the importance of 47 factors identified from the literature that were considered likely to affect construction productivity. Focusing on the 15 most influential factors in the study, the following figure is presented:

Figure 13: Main factors affecting productivity in the construction industry in Australia (Hughes and Thorpe, 2014: 220).

Rank	Factors	Rating on Likert scale 0	1	2	3	4	Total responses	Total scores	Rii
1	Rework	0	1	2	5	28	36	132	0.917
2	Incompetent supervisor	0	2	1	7	26	36	129	0.896
3	Incomplete drawing	1	2	6	14	13	36	108	0.750
4	Work overload	0	4	20	8	4	36	87	0.604
5	Lack of material	0	5	14	14	3	36	84	0.583
6	Poor communication	0	4	22	5	5	36	83	0.576
7	Poor site conditions	0	8	20	6	2	36	74	0.514
7	Poor site layout	0	8	20	6	2	36	74	0.514
7	Overcrowding	0	8	20	6	2	36	74	0.514
10	Inspection delay	1	13	11	6	5	36	73	0.507
11	Absenteeism	0	7	22	7	0	36	72	0.500
11	Worker turnover	0	7	22	7	0	36	72	0.500
13	Accident	0	8	25	3	0	36	67	0.465
13	Tools/equipment breakdown	0	8	25	3	0	36	67	0.465
13	Lack of tools and equipment	0	8	25	3	0	36	67	0.465

5. CROSSCUTTING ANALYSIS

The brief review of the international literature has shown that there are many different practices and metrics for measuring productivity and efficiency in construction.

Figure 14 below illustrates the different metrics used in the analysis of productivity and efficiency in the studies. These are the independent variables in the different studies.

Figure 14: Number of productivity metrics identified

Meta-descriptor	Number of metrics identified
Company characteristics	1
Costs	20
Defects	2
Efficiency	1
Energy	2
H&S	3
Information	1
Performance	1
Process	1
Project type	2
Quality	4
Quantity	4
Satisfaction	6
Sustainability	3
Technology	1
Time	9
N/A	1
Total	**62**

Not surprisingly, cost metrics are most prominent, but also time metrics and the more qualitative satisfaction metrics are seen as variables for the measuring of productivity.

Figure 15 below lists the grouped factors influencing productivity identified in the studies. It is seen that labour and process related factors are the most prominent in the studies. The process factors encompass a very wide variety of issues, including availability of construction equipment, communication between site management and labour force to incomplete drawings. Appendix 3: Raw data from the literature review contains the full list of factors.

Figure 15: Number of factors influencing productivity identified

Meta- descriptor	Number of factors identified
Company size	1
Contract	1
Economic situation	5
Environment	3
Labour	28
Location	8
Management	11
Market	1
Process	39
Project size	3
Project type	3
Regulation	3
Specialization	2
Technology	7
Wages	1
Company size	1
Total	**116**

Scrutinizing the relationship between factors and their actual impact on productivity, not that many studies had documented explicitly the relationship between factors and productivity development. Instead many studies only stated that there were factors impacting productivity. In such cases, we have chosen to record the factors without assuming what the relationships are.

The figure 16 below illustrates the relationships identified in the literature. Of more interesting finding can be mentioned the Norwegian study By Ingvaldsen and Edvardsen (2007) who document a negative correlation between increasing company size and increasing productivity, meaning that larger companies are less productive than smaller companies.

Figure 16: Correlation between grouped factors and productivity improvements

	Impact on productivity			
Meta-descriptor	**N/A**	**Negative**	**Positive**	**Total**
Company size		1		1
Contract	1			1
Economic situation		1	4	5
Environment	2	1		3
Labour	15	6	7	28
Location	6		2	8
Management	8		3	11
Market	1			1
Process	31	1	7	39
Project size	1	1	1	3
Project type	3			3
Regulation	2	1		3
Specialization	2			2
Technology	3	1	3	7
Wages		1		1
Total	**75**	**14**	**27**	**116**

The following figure 17 illustrates the 41 factors that have been identified with an explicit (negative or positive) impact of productivity in the studies.

Figure 17: Factors impacting productivity

Factor	Negative	Positive
Amount of pay		1
Availability of construction equipment on the job		1
Bonus agreement for salaried employees		1
Collaboration		1
Coordinated (centralized) purchasing agreements		1
Crashing (gaing lost time)		1
Crowded site		1
Declining unemployment	1	
Digitalization		1
Dining hall-and-dorm conditions		1
Economic follow-ups		1
Environmental Production paradigm	1	
External services	1	
Good macroeconomic development		1
Health-and-safety conditions		1
High ration of salaried to hourly paid workers	1	
Increasing (internal) migration		1
Industrialization		1
Labor disruption	1	
Lack of investment	1	
Large companies	1	
Lean methods		1
Low interest rates		1
material management		1
Material or labor cost escalation	1	
Meetings with unions	1	
on-time payment		1
Overtime	1	
Personal injuries	1	
Prefabrication		1
Project size	1	1
quality of site management		1
Relaxation allowances		1
Rework costs	1	
Rising wages	1	
Sanctions imposed by work env. authorities		1
Site layout		1
Supervision		1
Systematic flow of work		1
Working in social insurance		1
Total	**14**	**27**

Finally, we also present a figure illustrating the different productivity influencing factor identified in different countries. It is seen that process and labour related issues dominate in most countries whereas technology does not seem to play any prominent role. Of course, being based on a limited number of studies, and conducted in a rather short time span, the findings form the study are not necessarily representative. Moreover, the specific coding of the findings where we have grouped specific factors into meta-categories can also be open for debate, as some factors could be argued to belong to another group. Thus, for the sake of transparency, we have included the data and our coding hereof in Appendix 2: Coding of data so the readers can make up their own minds.

Figure 18: Number of productivity influencing factors identified in different countries

	Australia	Denmark	Egypt	Gazza Strip	Germany	India	Kuwait	Norway	Palestine	Qatar	Turkey	Uganda	UK	Total
Company size								1						1
Contract		1												1
Economic sit.					3						2			5
Environment								1		1			1	3
Labour	3		3	1	2			5	1	4	4	1	4	28
Location	2	1			1			1			1		2	8
Management	2		1	1						2	5			11
Market					1									1
Process	8		1	3		1	2	7	3	3	2	2	7	39
Project size		1						1					1	3
Project type							1		1				1	3
Regulation								2					1	3
Specialization					1								1	2
Technology					3			3					1	7
Wages					1									1
Total	**15**	**3**	**5**	**5**	**12**	**1**	**3**	**21**	**5**	**10**	**14**	**3**	**19**	**116**

Limitations and reflections

A lot of the reported studies and industrial initiatives are moreover 'flawed' in the sense that the methodological bases of the studies are highly unsure and questionable. This is due to a lack of description of assumptions, variables, data collection methods, as well as calculations/analytical approaches.

Moreover, the different studies report data differently making it very difficult to draw comparisons across the data sets. Even when studies seemingly report the same figures (e.g. square meter costs) inconsistencies in data collection or quality of data makes comparisons dubious. There is also difference in the scope of the findings, in that some

initiatives measure data on an industrial level (typically labour productivity based on data for the national statistical bureau) whereas others focus on project level data and some on organization level KPIs and data.

Another factor that makes comparison difficult, and which have not been addressed explicitly in the studies, is that different national contexts most likely will have an impact on the factors that influence productivity. Differences in market structure, regulations, building technologies, etc. will vary and influence building processes in different ways.

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APPENDIX 1: STUDIES AND SOURCES

Figure 19: Studies and sources

ID	Initiative/Source	Notes
1	Koch, C. and Lundholm, M. (2018) PRODUKTIVITETSLÄGET I SVENSKT BYGGANDE 2014, Lokaler, Gruppbyggda småhus och Anläggning	Survey distributed to 500 companies. Self-reported cost figures form clients and site managers. Responses from 580 persons (full or partial)
2	Byggeriets Evaluerings Center	Voluntary benchmark scheme. Contains data reported by 189 member companies that register projects for benchmarking
3	Constructing Excellence	Quango. Industry initiative with governmental support. Published annual reports with industry KPI's. Have not correlated KPIs or discussed factor influencing productivity. Defined value added as gross turnover less all bought-in supplies. Data obtained from firms filing annual accounts with Companies House.
4	Die deutsche Bauindustrie (2018) Kapazitätssituation im deutschen Bauhauptgewerbe, Berlin, Hauptverband der Deutschen Bauindustrie	Die deutsche Bauindustrie (2018) Kapazitätssituation im deutschen Bauhauptgewerbe, Berlin, Hauptverband der Deutschen Bauindustrie.
5	Bundesvereinigugn Bauwirtschaft	Based on price databases from the Arbeitsgemeinschaft für zeitgemäßes Bauen e.V. (ARGE)
6	Byggekostnadsprogrammet	Government initiative with participation form more than 200 differenct companies. Three focus ares one of which is increased productivity with focus on reduced defects, increased efficience, lowered conflicts and improved quality.
7	Måling av produktivitet og prestasjoner i byggenæringen	https://dibk.no/globalassets/bygg21/problemnotat---produktivitetsmaling-i-byggenaringen.pdf

8	CII	https://www.construction-institute.org/resources/knowledgebase/best-practices/benchmarking-metrics/topics/bmm-productivity https://www2.construction-institute.org/nextgen/learn.cfm
9	Besparelsespotentialer for det offentlige ved længerevarende samarbejder i byggeriet	http://produktivitetskommissionen.dk/media/127755/Dansk%20Byggeri.pdf
10	Effektivitetsanalyse av byggeprosjekter	Ingvaldsen, T. and Edvardsen, D.F. (2007) Effektivitetsanalyse av byggeprosjekter, rapport 1, SINTEF Byggforsk.
11	Effektivitet og produktivitet i bygging av veier i Norge 2007-2016	Rødseth, K.L., Holmen, R.B., Førsund, F.R. and Kittelsen, S.A.C. (2019) Effektivitet og produktivitet i bygging av veier i Norge 2007-2016, Concept-rapport nr. 56, Ex ante akademisk forlag.
12	Construction Leadership Council	Construction Leadership Council (2018) Housing Industry Metrics, October 2018, Innovation in Buildings Workstream, Construction Leadership Council.

APPENDIX 2: CODING OF DATA

Figure 20: Example of coding of employed metrics according to meta-descriptors

Meta-descriptor	Metrics employed in the identified studies
Company characteristics	- Company characteristics
Costs	- Actual costs - Capital cost of completed homes (£) - Capital cost/m2 - Cost of post construction defects (£) - Cost per produced square meter - Costs - Predictability Cost - Construction - Predictability Cost - Design - Predictability Cost - Project - Preliminaries (£) - Prelims cost per home built - Pre-manufactured value (PMV) - Productivity - Productivity (VAPE Constant 2016 Values) - Productivity (VAPE Current Values) - Profitability - Site Labour Cost (£) - Square meter costs - Value Added per hour worked
Defects	- Defects - Defects - Impact at Handover
Efficiency	- Square meter efficiency
Energy	- Embodied carbon - EPC rating
Information	- Provision of Information
Performance	- Performance - Overall
Process	- Payment
Project type	- Project type - Project/building size and characteristics (multiple)
Quality	- ISO 9001 Accreditation - Quality rating - Quality/standard - Rework

Quantity	- Gross internal floor space of completed homes (m2) - Homes completed - Number of homes completed - Changes
Satisfaction	- Client Satisfaction - Product - Client Satisfaction - Service - Client Satisfaction - Value for Money - Contractor Satisfaction - Customer satisfaction
Sustainability	- Energy - Energy consumption - Waste generated
Technology	- BIM Level 2
Time	- Days elapsed on site - Days on site/m2 - Lead time - Man hours on site - Predictability Time - Construction - Predictability Time - Design - Predictability Time - Project - Time consumption - Schedule
H&S	- Accidents - H&S - Safety

Figure 21: Example of coding of identified factors according to meta-descriptors

Meta-descriptor	Factors identified in the identified studies
Company size	- Large companies
Contract	- Contract forms
Economic situation	- Amount of pay - Good macroeconomic development - Lack of investment - Low interest rates - on-time payment
Environment	- Environmental Production paradigm - High temperature weather - Weather / Climate

Labour	-	Absenteeism
	-	Accident
	-	Availability of Skilled Labor
	-	Bonus agreement for salaried employees
	-	competency of labor supervision
	-	Core project team turnover
	-	Declining unemployment
	-	Dining hall-and-dorm conditions
	-	Health-and-safety conditions
	-	High ration of salaried to hourly paid workers
	-	incentive programs
	-	Increasing (internal) migration
	-	Labor disruption
	-	labor experience and skills
	-	lack of craft worker skill
	-	lack of labor experience
	-	lack of providing labour with transportation
	-	Material or labor cost escalation
	-	Overtime
	-	Personal injuries
	-	proportion of work subcontracted
	-	Relaxation allowances
	-	Sanctions imposed by work env. authorities
	-	shortage of experienced labour
	-	skill of labour
	-	Worker turnover
	-	Working in social insurance
Location	-	Crowded site
	-	Geographic location
	-	Geographical differences
	-	Poor site conditions
	-	Poor site layout
	-	Project nature
	-	Site Conditions
	-	Site layout
Management	-	Incompetent supervisor
	-	Inspection delay
	-	labour supervision
	-	lack of construction managers' leadership
	-	lack of labour surveillance

	- leadership and competency of construction management - material management - quality of site management - Supervision
Market	- Individual market segments
Process	- Availability of construction equipment on the job - availability of the material and ease of handling - clarity of technical specifications - Collaboration - communication between site management and labour forc - Coordinated (centralized) purchasing agreements - coordination level among design disciplines. - Crashing (gaing lost time) - delays in responding to “Requests For Information” - drawings and specification alteration during execution. - Economic follow-ups - Engineering Deliverables - Engineering work sequence - Incomplete drawing - lack of cooperation and communication between construction parties - lack of material - lack of materials - Lack of tools and equipment - Lean methods - material shortage - material unavailability - Materials Availability/Cost - misunderstandings between labour and superintendent - on-time payment - Overcrowding - Poor communication - Project team communication - Project team expertise - Quality assurance - rework - Rework costs - shortage of materials - Systematic flow of work

	- Tools/equipment breakdown - Use of multiple design offices - Work overload
Project size	- Project size
Project type	- Project type - Financial status of owner - Extent of variation
Regulation	- Meetings with unions - Regulation - Regulatory requirements
Specialization	- Project complexity - Variation of buildings
Technology	- Building materials - Digitalization - External services - ICT - Industrialization - Prefabrication - Use of offshore (remote) engineering
Wages	Wages - Rising wages

APPENDIX 3: RAW DATA FROM THE LITERATURE REVIEW

Figure 22: Type and contents of sources.

ID	Country	Productivity definition	Level of analysis	Type	Methodology	Input	Output
1	Sweden	Output-input	Project level	Scientific study	Survey	Self-reported data	Cost per produced square meter
2	Denmark	None	Project level	Industry database	Voluntary reporting	Self-reported data	Cost per produced square meter
3	UK	Output-input	Industry level	Industry survey	Survey	Annual accounts	Value added per employee
4	Germany	Labour input	Industry level	Industry report	National statistics	National statistics	Value added per hour worked
5	Germany	None	Project level	Industry report	Price database	Model	Cost per produced square meter
6	Norway	None		Industry initiative	Demonstration projects		Reduction of defects
7	Norway	Gross product Labour productivity Total fact productivity	Meta-analysis	Scientific study	Litrature review		
8	USA	Direct work hours / installed quantity	Project level	Industry-university consortium	Mixed	Self-reported data	
9	Danmark		Project level	Scientific study	Cost calculation	Actual cost	Cost per produced square meter

10	Norway	Product (quantities) / resources (resources spend). Total factor productivity	Project level	Scientific study	Survey	Actual cost	Performance indicators and KPIs: - Square metre costs - Time consumtion per square metre - Square metre efficiency - Misc. Performance indicators
11	Norway	Production / resources	Multi-level	Scientific study		Actual cost	Cost per meter
12	UK	Labour productivity.	Industry level	Industry study	KPI system	BRE's April 2018 report	KPIs

Figure 23: Factors and additional data identified in the literature

ID	Factors influencing productivity	Additional data collected
1	Disturbances Project organization Contract forms Production techniques Project size	N/A
2	Contract forms Project size Geographic location	Lead time Defects Accidents Customor satisfaction Energy consumption
3	N/A	Client Satisfaction - Product Client Satisfaction - Service Client Satisfaction - Value for Money Contractor Satisfaction - Performance - Overall Contractor Satisfaction - Provision of Information - Overall Contractor Satisfaction - Payment – Overall2 Defects - Impact at Handover Predictability Cost - Project Predictability Cost - Design Predictability Cost - Construction Predictability Time - Project Predictability Time - Design Predictability Time - Construction Profitability Productivity (VAPE Current Values)

		Productivity (VAPE Constant 2016 Values)
4	Low interest rates Good macroeconomic development Declining unemployment Rising wages Increasing (internal) migration Lack of investment Prefabrication Digitalization	
5	N/A	N/A
6	Quality assurance ICT Industrialization Lean methods Collaboration Regulation	N/A
7		
8	Project type, size and nature. Project impact factors include: Labor Disruption Engineering work sequence Owner site requirement Engineering Deliverables Weather / Climate Availability of Skilled Labor Materials Availability/Cost Site Conditions Project complexity Regulatory requirements Project team expertise Project team communication Core project team turnover Use of offshore (remote) engineering Use of multiple design offices Material or labor cost escalation Construction productivity Availability of construction equipment on the job	Performance metrics include cost, schedule, safety, changes, and rework. Construction productivity metrics are categorized according to concrete, structural steel, electrical, piping, instrumentaion, equipment, insulation, scaffolding
9	Project size	none
10	In project with high efficiency PM - used much time on economic follow up, caught op on delays fast and did not allow much overtime work Unconfirmed hypotheses: - Olso location does not correlate with low efficiency - Efficiency and production pace is uncorrelated - Differences in number of subcontractors do not correlate with differences in efficiency	Project ID Project type Company characteristics Project/building size and characteristics (multiple) Quality/standard Energy H&S etc.

	- Differences in project size do not correlate with differences in efficiency - High degree of repetition does not correlate with high dgree of efficiency - Different prefabrication degree does not give rise to differences in efficiency	
11	N/A	N/A
12	N/A	Housing industry metrics consists of multiple parameters. On cost data, the following data is collected: - Number of homes completed - Gross internal floor space of homes (m2) - Capital cost of completed homes (£) - Days elapsed on site - Man hours on site - Preliminaries (£) - Site Labour Cost (£) - Cost of post construction defects (£) Metrics include: Capital cost/m2 Embodied carbon Days on site/m2 Homes completed Productivity Pre-manufactured value (PMV) EPC rating Quality rating BIM Level 2 Waste generated ISO 9001 Accreditation RIDDOR Prelims cost per home built

APPENDIX 4: FIGURE LIST