Construction productivity revisited

towards measuring performance of construction output

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Construction productivity revisited: towards measuring performance of construction output

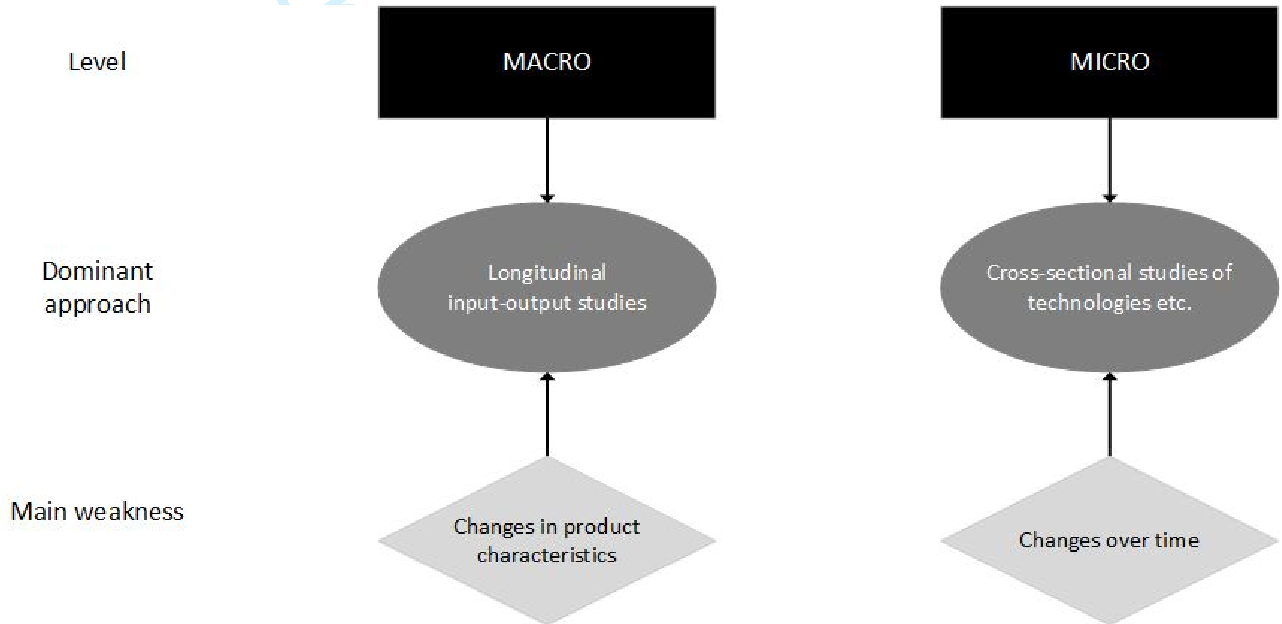
Abstract

- Purpose
  - Construction is repeatedly criticised for its low productivity based on statistical data that do not represent the output of construction adequately. The purpose of this study is to improve our understanding of construction output – being the numerator in construction productivity calculations – by focusing on changes in quantity of the products, product characteristics and composition of the aggregate rather than as changes in price.
- Design/methodology/approach
  - The research design of this study applies statistical data from the national accounts along with data from four paradigmatic case studies of social housing projects covering a period of 50 years.
- Findings
  - The results indicate that while construction output prices have increased almost three-fold over the past 50 years, improvements in performance can only explain approximately 20%.
- Research limitations/implications
  - The developed four-step method has demonstrated its value as a means to measure changes in the characteristics of the product, but more studies on the actual figures and results over time and regions are required before solid conclusions can be drawn.
- Social implications
  - This study has added new knowledge of construction output that supports the development of a more accurate construction statistics, which in turn can assist the design of more effective and evidence-based policies for improving construction productivity.
- Originality/value
  - This paper describes and demonstrates a novel performance-based methodology for addressing changes in the characteristics of the products in a longitudinally perspective, which can potentially provide a better understanding of changes in productivity.

INTRODUCTION: BRIDGING THE GAP

Studies on construction productivity tend to fall in two main lines of inquiry – micro-level studies focusing on e.g. different construction technologies and macro-level studies focusing on input-output studies of national accounts. However, these two lines of inquiry seem to be disconnected and may even arrive at very different conclusions with regard to construction productivity. Hence, this paper attempts to bridge the gap between these two lines of inquiry by combining construction productivity data from input-output studies with measurements at micro-level of changes in the product, namely the building. This may in turn improve the measurement of construction output, which is the numerator in the calculation of construction productivity (Figure 1).

Figure 1. Level of perspective, dominant research approach and main weaknesses in productivity studies



While a number of micro-level studies on construction productivity have compared different construction technologies across countries, identified critical factors, etc., few, if any, studies apply a *longitudinal* perspective to look more closely into the long-term changes of the characteristics of the product. On the contrary, the micro-oriented literature goes to great lengths to select technologies and projects that are similar to each other, hence comparable, in order to make cross-sectional studies at a specific point of time. This paper adopts the opposite position and explores how a longitudinal perspective on a particular subsector of construction, namely social housing, may generate new insights that may improve our understanding of how to measure construction productivity development by focusing on the changes in costs and product characteristics over time.

On the other hand, macro-level studies of construction productivity, in particular input-output studies of national accounts, often adopts a longitudinal perspective but have very little understanding of the product in question. Calculations of construction productivity and its often surprisingly low level in comparison to other economic sectors are usually based on changes in price, which does not reflect changes in volume and quality. Furthermore, productivity statistics mostly operate with aggregate figures and do not separate between construction sub-sectors. The character of production in civil engineering, new building construction and building maintenance and repair, however, varies tremendously as regards technological development and the composition of intermediate goods and other inputs, which in turn determines productivity development. In this paper, the importance of disaggregating construction productivity is analysed as well as it is explored how productivity measures to a greater extend could reflect changes in the compositional change of building volume as well as changes in characteristics of the products delivered.

Indeed, the statistical methods applied for measuring the productivity of building and construction are generally classified at the poorest level C as categorised by Eurostat (2001). The main reason is the use of deflators in which the value added by the building and construction sector is deflated with a cost index. A deflator is a figure that allows data to be measured and compared over time in terms of specified base period. Hence, the problem with the current deflator in the national accounts is that changes in quality over time are measured by *changes in price*, not as *changes in volume* as it should be (Produktivitetskommissionen, 2013a). The volume index can be broken down into three principal components (Eurostat, 2001: 4):

- *"changes due to changes in the quantity of the products,*
- *changes due to changes in the characteristics of the products, and*
- *changes due to compositional changes in an aggregate."*

Danish national statistics apply square metres distributed on building type and country region as volume index and thereby implicitly assume that the standard or quality of floor areas does not change over time (Danmarks Statistik, 2002). This points to a need for developing more suitable measurements of construction output that are capable of addressing changes in the *quantity* of the products, changes in the *characteristics* of products, and changes in the *composition of an aggregate*. This study suggests that improved methods for measuring changes in volume will reveal that construction is far better than its reputation. The hypothesis then is that construction will display a higher level of productivity development due to improved product characteristics over time.

This study does not intend to develop a new deflator as such, but aims at improving our understanding of the underlying changes in the volume index. It is our hope that this will foster new studies by interdisciplinary teams of economists and building researchers who can jointly develop such deflators. Hence, the purpose of this paper is to:

(1) identify changes in the composition of the Danish construction aggregate;
(2) develop a novel method for identifying and measuring changes in the characteristics of the product; and
(3) discuss output price developments in relation to changes in the characteristics of the product.

Drawing on and extending previous studies reported in Danish by Larsen (2006) and Nielsen et al. (2010), this study focuses on a particular segment of Danish construction, namely social housing, in order to ensure comparability over time and to ensure access to detailed information from the construction period. This study covers four social housing projects over a period of 50 years: One from 1957 representing traditional craft production, one from 1970 representing early industrialisation, and two from 2005 representing two different styles of contemporary social housing.

RESEARCH METHODOLOGY

The research design of this study combines a literature review with analysis of statistical input/output data and four paradigmatic case studies in order to provide a deeper understanding of how to measure changes in the volume index constituting the numerator when measuring construction productivity.

First, this study reviewed an extensive amount of literature available through Google Scholar, EBSCOhost and Emerald Insight using the search phrases "construction productivity", "building productivity" and "labour productivity". These search phrases were varied in a number of ways by adding other relevant search phrases like "measurement", "input-output", "deflators", etc. While the search phrase "construction productivity" generated only around 7,500 hits by Google Scholar, adding the term measurement to this search phrase exploded the number of hits to close to 1.7 million – an insurmountable number to review. Hence, the searches were delimited using different time spans, using different combinations of Boolean operators, following particular important scholars within the field, and focusing on selected journals. A special focus was put on particularly important journals within the construction field like "Construction Management and Economics", "Construction Innovation", "Engineering, Construction and Architectural Management", "Facilities" and "Journal of Facilities Management" as well as journals in neighbouring fields like "Journal of Management in Engineering", "International Journal of Productivity and Performance Management" and "International Journal of Operations & Production Management". While the literature review may not be exhaustive and cover the field in its entirety, it is selective by highlighting a range of the most significant studies over the past 30-50 years with an emphasis on more recent studies.

Second, this study extracted and analysed a set of publicly available construction statistics from Statistics Denmark using the online database Statistikbanken. This part of the study include a range of statistics covering national accounts, tables listing productivity development for different business types, production volume distributed on different subsectors, number of employees and man-hours delivered, labour productivity in different subsectors (new buildings, renovation, civil engineering works), etc. As stated in the OECD manual on productivity, measuring productivity is basically about comparing "*a volume measure of output to a volume measure of input use*" (OECD, 2001:12). The most frequently used ways of calculating productivity compute output – gross output or value added – against input – capital and labour. The single most frequently used measurement applies output in the form of gross value added and input of labour, and thus calculates labour productivity. Likewise, capital productivity can be calculated. Multifactor productivity either computes inputs of labour and capital on the basis of value added as output, or input is in the form of capital-labour-energy-materials (and services) based on a concept of gross output (OECD, 2001:13). If we take the Danish construction sector as an example, Statistics Denmark, in accordance with the OECD Manual, publishes data on productivity based on output in the form of gross value added computed against a multifactor input comprising labour, IT capital, other capital (equipment), educational level and a residual termed total factor productivity originating from improved work organisation, etc.

Third, this study was based on four exemplary case studies (Flyvbjerg, 2005) representing archetypical ways of building social housing projects in three distinctively different periods of building technology, namely 1957, 1970 and 2005:

- residential buildings dating from 1953 - 1957 – traditional craft production
- residential buildings dating from 1968 - 1972 – early industrialisation
- residential buildings dating from 2003 - 2007 – contemporary building customs

The selected buildings all had to meet the requirements of having undergone very modest modernisations in order to study the original construction. All of the buildings are located in the metropolitan area to avoid cost differences due to regional differences. The social housing company KAB provided the study with a list of 10 residential projects meeting these requirements. Among the group of older buildings, those with the least modernisations were selected. The study included two new projects. As the final accounts of the firstly selected project was delayed, it was decided to include a second project. In the meantime, registrations were made regarding the first project. As accounts eventually became available before the research project ended, it was decided to include both projects in the study. The four projects cover:

- Herman Bangs Plads: The building consists of 5 floors and a basement. It houses 18 apartments distributed on two staircases with shops on the ground floor. The building was built in 1957 as a traditional brick building with hollow slabs and tile roof. The building width is 10 m.

- Sjælør Boulevard: The building is a very large complex consisting of 2 blocks of 4 floors and 2 blocks of 8 floors with a total of 544 apartments. It was built in 1970 with prefabricated concrete slabs, brick walls and roofing felt. The building width is 15.41 m.
- Emaljehaven (Marstrands Have): This is a mixed-ownership building – private condominiums and social housing managed by KAB. The non-profit part houses 60 apartments. The building consists of one housing block with two side wings. The building has 5 floors and a basement. The building was constructed as a concrete building construction in 2005-06. The roof has a slope of 1:40 and is covered by roofing felt. The building width is 11.88 m.
- Havnestaden: The building was built in 2005 and consists of 6 floors and a basement. It houses 30 apartments distributed on 3 staircases. The inner walls are made of concrete and the facades are made of external insulation with plaster. The roof is made with roof cassettes covered by 2 layers of roofing felt. The building width is 11.87 m.

The social housing company KAB provided the study with account figures from the year of completion of the four projects split in four main costs groups for building land, contractors, consultants and other costs, which has been customary within social housing for a prolonged period of time. The selection of key parameters for comparing product characteristics were based on changes in the Danish Building Regulations, development in building technology and development in user requirements.

A specific apartment in each residential building was selected in order to obtain detailed data for comparison of product characteristics. The apartments had approximately the same net areas (67 to 73 m^2). The housing company made final accounts of the projects, building specifications, apartment plans, and drawings showing buildings details available. The buildings were visited for external inspection, and observations were recorded by photography and field notes. During the visits, information in construction documents was supplemented with data provided by residents about renovation works, choice of technical solutions and the nature of surfaces, etc.

PREVIOUS STUDIES ON CONSTRUCTION PRODUCTIVITY

Productivity development continues to receive immense attention for example from a number of international institutions like the OECD (OECD, 2015), the European Central Bank (European Central Bank, 2016) and the European Commission (European Commission, 2014). This interest is also highly visible on a national level. In 2012, the Danish government established an independent Productivity Commission to look more closely into the problem of weak productivity development in all Danish private business sectors as well as in the public sector. In its first report addressing the nature of the productivity problem, the Danish Productivity Commission explicitly stated that statistical data in the national accounts do not provide an accurate picture of the productivity development in the building and construction sector due to the applied deflators (Produktivitetskommissionen, 2013a).

On a national level, construction productivity has been a recurrent theme over the past 60 years. A series of studies were conducted in the 1950s-90s concerning the composition of prices that form the entire price of a building (Byggeriets bestanddele, 1952; Arctander and Christiansen, 1965; Arctander and Christiansen, 1966; Fællesorganisationen af almennyttige danske boligselskaber, 1970; Byggeriets Udviklingsråd, 1990; Høgsted, 1995). These studies primarily focus on the use of manpower in terms of man-hours rather than labour costs, which was an important issue in the early industrialisation of the construction sector. Other national studies identify barriers for improving construction productivity (Clausen et al., 1994; Kristiansen et al., 2005). During the past 20 years several policy studies have been concerned with construction productivity. The apparently flat curve showing the absence of productivity development from 1966 onwards has been used as a platform for launching a range of different policy initiatives to improve performance of the construction industry (Erhvervsfremme Styrelsen, 1993 & 2000; Byggepolitisk Task Force, 2000; Erhvervsog Byggestyrelsen, 2009 & 2011). These studies and policy analyses have to a varying degree and with different methods tried to measure construction productivity, but they did not address changes in the characteristics of the product.

In early 2014, the Danish Productivity Commission concluded its work with the publication of six main reports and a synthesis report on wealth and welfare supported by a number of background reports. The Danish Productivity Commission pointed out that the composition of the building and construction sector as an aggregate has changed significantly over time with less output as civil engineering works and moving from new buildings towards renovation activities. As many companies perform all three types of activities, it is difficult to distinguish between them. The distribution on each of the three subsectors is therefore based on estimates. Consequently, the Danish Productivity Commission (Produktivitetskommissionen, 2013a and 2013b) called for the establishment of a working group with representatives of Statistics Denmark and the industry to develop a new set of more appropriate statistics to continue previous work by Statistics Denmark (Danmarks Statistik, 2010).

The issue of construction productivity has also been a recurrent theme in the international academic literature for a long time. Industry level studies of construction productivity typically direct attention toward input-output studies of sectoral competitiveness and various techniques, tools and databases to improve the measurement of construction productivity. Input-output studies have become a popular subject with several studies covering individual countries like e.g. Italy (Pietroforte and Bon, 1995), China (Wu and Zhang, 2005), Denmark (Pietroforte and Gregori, 2006), Thailand (Kofoworola and Gheewala, 2008), and Turkey (Gundes, 2011). Other studies focus on cross-country comparisons of e.g. highly developed economies (Pietroforte and Gregori, 2003; Abdel-Wahab and Vogl, 2011), emerging markets (Gregori and Pietroforte, 2015) and developed versus less developed countries (Choy, 2011). Some studies focus on measuring and comparing the competitiveness of a national construction sector with other business sectors and with other nations (Ive et al., 2004) or the effect of the financial crisis (Ma and Liu, 2014). A number of critical studies calls for improving the quality of data and methods (Best and Langston, 2006; Ruddock, 2002), extending measurements to include carbon reduction (Hu and Liu, 2017) or suggesting alternative methods for measuring productivity development (e.g. Gruneberg and Folwell, 2013; Li and Liu, 2009; Ruddock and Ruddock, 2011; Hu and Liu, 2016).

An important area of research in relation to input-output studies is related to the critical assessment and development of deflators for output price indexes applied for comparisons of figures over time. This line of work focuses on developing implicit or explicit price indexes to distinguish between changes in the money value of the gross domestic product resulting from a change in prices a change in physical output. De Valence (2001) reviews output price deflators and identifies a number of problems found in adjusting current prices to constant prices using these deflators which include deflation techniques, measurement of output quality and capital inputs, and the use of input price indexes for labour and materials. Some authors like Bröchner and Olofsson (2011) suggest adjusting deflators by extending the range of output quality variables in input-output studies via the increasing volume of performance indicator data collected for construction project benchmarking. In a similar vein, Vogl and Abdel-Wahab (2015) argue that cross-country productivity at the project level can enable a more detailed analysis of the tangible and intangible inputs to the construction process while accounting for the heterogeneous nature of the industry, e.g. through an international benchmarking club. In a recent study, the U.S. Bureau of Labor Statistics (Sveikauskas et al., 2016; 2018) developed an alternative and more reliable measure of output price deflators to cover four sub-industries: single-family residential construction; multifamily residential construction; highways, roads, and bridges construction; and industrial construction. This study mirrors similar work on an output price index for prefabricated standard houses in Germany (Danmarks Statistik, 2010) and recent developments in Danish national statistics (Danmarks Statistik, 2014).

Another type of studies focus on the identification of critical factors that advance or inhibit construction productivity like the repetition effect (Tucker, 1986; Hijazi et al., 1992; Gottlieb and Haugbølle, 2010; Pellegrino et al., 2012; Zhai et al., 2009; Chancellor, 2015). Others focus on developing conceptual frameworks and strategies for improving construction productivity (Cottrell, 2006; Park, 2006; Yu et al., 2007; Goodrum et al., 2010; Jang et al., 2011; Abdelhamid and Everett, 1999). As pointed out by Park (2006) and later repeated by Pellegrino et al. (2012), most studies tend to collect data on one or two factors to establish the relationship between productivity and the identified factor(s). Some notable exceptions to this general pattern do exist which focus on multi-factor analysis based on data from larger cohorts of actual projects as part of research projects or established institutions like e.g. the Construction Industry Institute in the USA (Park et al., 2005; Allmon et al., 2000; Ingvaldsen and Edvardsen, 2007).

At micro or project level, a range of studies compares different types of construction technologies in order to assess their relative competitiveness against other technology. Structural frames in particular have received attention. In his study of the cost performance of technologies, typically used in medium-rise 10-floor commercial buildings, Mills (2013) points out that the Australian construction industry has a long cultural preference for using in situ concrete for structural frames. As stated by Pellegrino et al. (2012) structural frames are important as they always appear on the critical path of project scheduling and represent a significant proportion of costs. Pellegrino et al. (2012) studied 15 comparable multi-storey concrete structures in Southern Italy and identified variable productivity rates. They attribute the variation to the repetitive work that characterises these structures, which according to learning curve theory provides distinct opportunities for productivity improvements. In their comparative study of the construction of similar types of in situ concrete high-rise buildings in Germany, UK and France, Proverbs et al. (1999a) show that significant productivity rate variations are observed for reinforcement fixing and formwork erection, while variation in productivity rates of concrete placing are not found to be dependent upon construction resource/method factors. Further, Proverbs et al. (1999b) found the performance of UK contractors to be more widely dispersed than the performance of French or German contractors. Leading UK contractors can compete with the best on the Continent, but there are a number of contractors whose performance is far worse than any in France or Germany, due mainly to the use by UK contractors of traditional timber formwork methods rather than the proprietary or prefabricated systems more widely used on the Continent.

Summing up, the question is to what extent macro-level as well as micro-level studies have contributed to our understanding of the three problems of measuring construction output appropriately with regard to changes in value/volume due to changes in the quantity of the products, the characteristics of the products, and the compositional changes in the aggregate. With regard to compositional changes in the construction aggregate, there seems to be a fair degree of consensus among scholars that a shift from new buildings to maintenance has taken place across the developed countries. With regard to the quantity of products, there is still significant dispute as to how to measure construction output adequately despite the launch of the EU KLEMS database and recent advances to disaggregate the output on a more detailed level of sub-industries. With regard to characteristics of the product, the literature is scarce and little consensus seems to exist as to how to measure these characteristics. The paper will address this issue in detail below and suggest a method to measure these changes in characteristics of the construction output longitudinally.

CHANGES IN THE COMPOSITION OF THE AGGREGATE: INPUT/OUTPUT STATISTICS

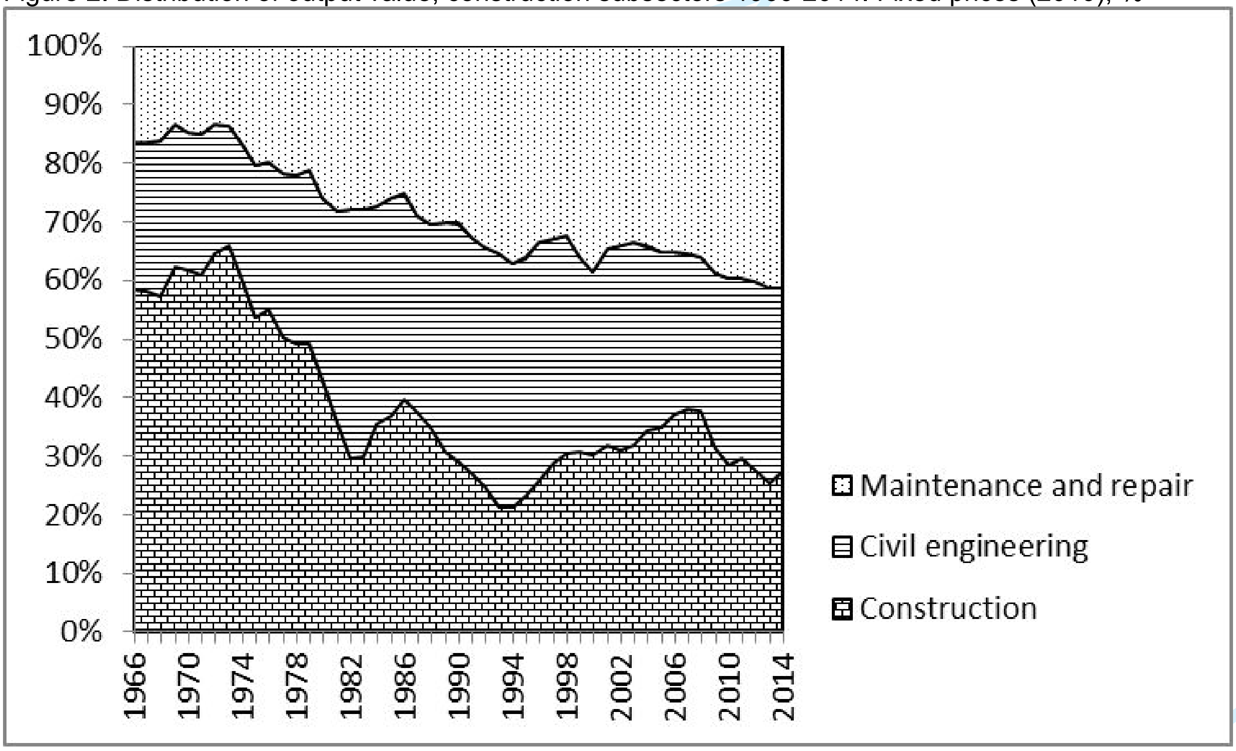
Despite the inaccuracies pertaining to methods traditionally used for measuring construction sector productivity, the fact that the construction sector encompasses a wide range of not necessarily comparable activities further complicates assessment of productivity development. Aggregating too much means compounding dissimilar activities where productivity development may vary from next to nothing in one construction subsector to levels comparable to those of the manufacturing sector elsewhere within construction. Even though data for different subsectors are available from Statistics Denmark, it does not diminish the earlier mentioned ambiguity resulting from the underlying productivity measurement methodology. Having this in mind, we now proceed to taking a closer look at changes in volume and productivity of the three construction subsectors in Denmark.

Construction output

The output value of the entire construction sector output amounted to DKK130 billion in 1966 in fixed 2010 prices. In 2014, the corresponding value was DKK177 billion. For almost 50 years, the lowest value was DKK123 billion in 1981 while the highest output value occurred in 2006 at DKK220 billion. Whereas the overall growth during almost five decades was modest measured in fixed prices, the distribution of output across construction subsectors – construction of new buildings, civil engineering, and professional maintenance and repair – changed significantly.

As illustrated by Figure 2, the share of new construction peaked in 1973 with 65%, the last year before OPEC's first major hike in oil prices. In 1994, it was at its lowest with only 21% and in 2014 the share of new building construction amounted to 28% of the total construction output. In absolute figures, new construction reached DKK113 billion in 1974 against DKK49 billion 40 years later in 2014. Civil engineering's share has not changed dramatically, although some points are remarkable: in the early 1980s and early 1990s the share reached 42-43% of total construction output. Civil engineering started out at 25% in 1966 and reached 31% in 2014, more or less corresponding to an average share of 32% during all 48 years. With civil engineering at a relatively stable share, the major shift in shares took place between new buildings and maintenance and repair work, the latter developing from a 17% share in 1966 to a 41% in 2014. Evidently, this was caused by changes in demand. Until the mid-1970s, housing shortage was substantial and economic growth significant. Since then different periods of economic recession in combination with a generally lower demand for new construction resulted in a new construction output at roughly half the level of the 1960-70s.

Figure 2. Distribution of output value, construction subsectors 1966-2014. Fixed prices (2010), %



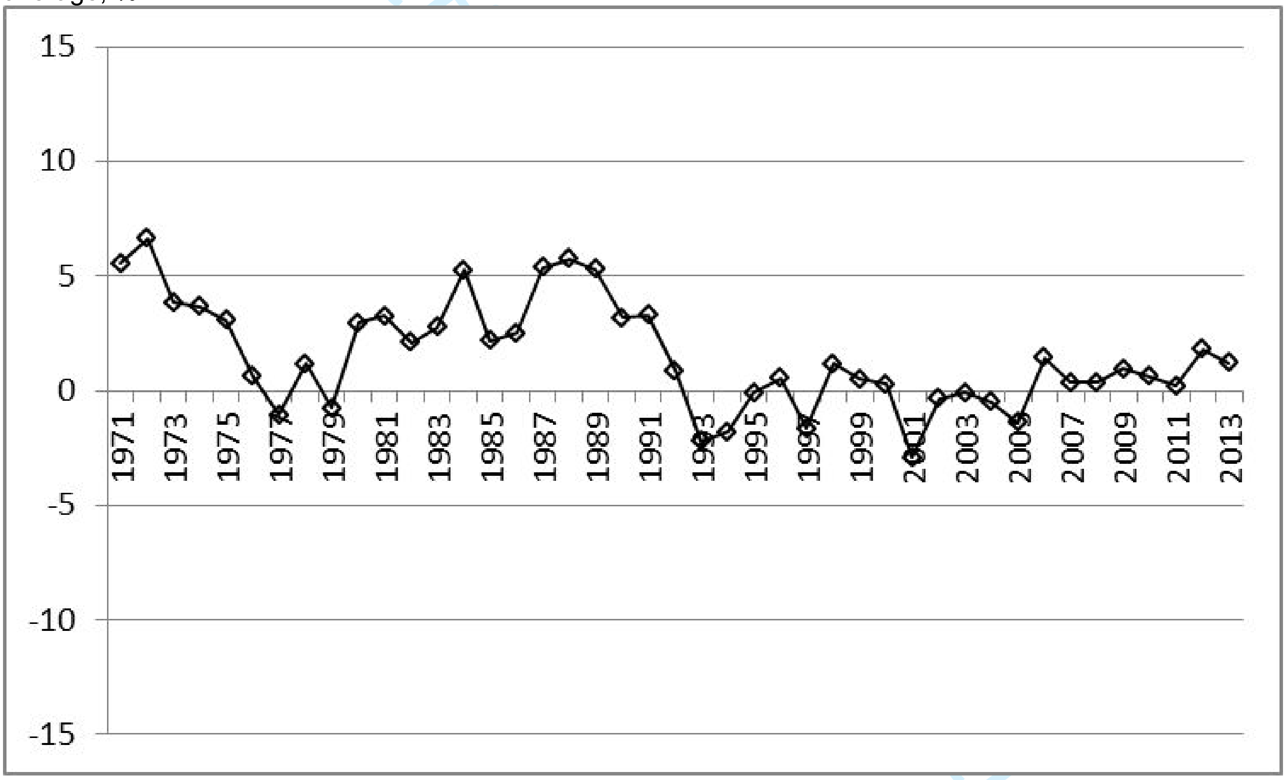
Source: Statistics Denmark (2018). National Accounts, Table NABP117

Overall, the composition of the aggregate has fundamentally changed by 2014 compared with 40 years earlier, where construction of new buildings amounted to two thirds of all production. In 2014, it amounted to less than one-third. The share of maintenance and repair work had more than doubled and currently amount to more than one-third. This fundamental shift in shares obviously influences the development of construction productivity.

Productivity growth rates

Figure 3 displayed annual average growth rates in labour productivity for the sum of construction, civil engineering and maintenance combined. Overall, annual productivity growth rates were distinctly higher in the first part of the period compared with the second half. Between 1993 and 2005, annual growth rates were negative in 8 of 12 years. Productivity growth rates did not become positive again until 2006, however at a modest level ranging between 0.2 and 1.8% annually.

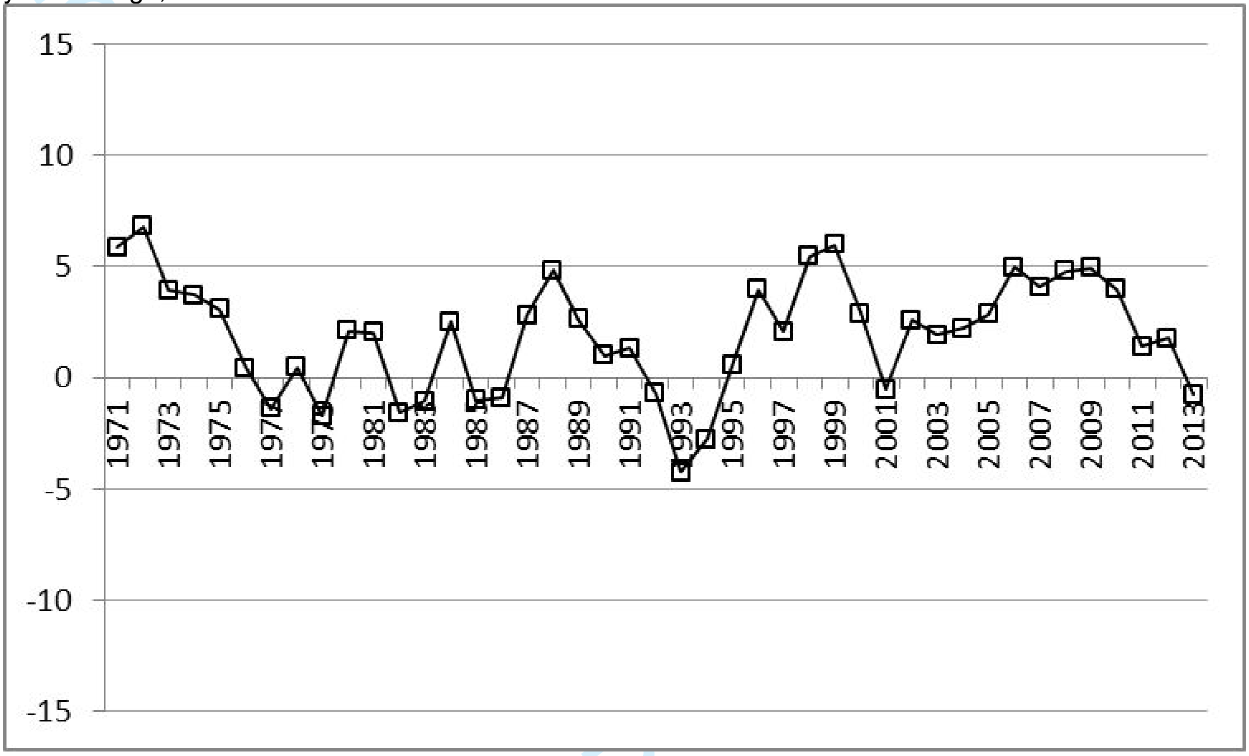
Figure 3. Labour productivity, all construction sectors 1971-2013. Annual growth rate, 2010 prices, 5-year average, %



Source: Statistics Denmark (2018). National Accounts, Table NP3

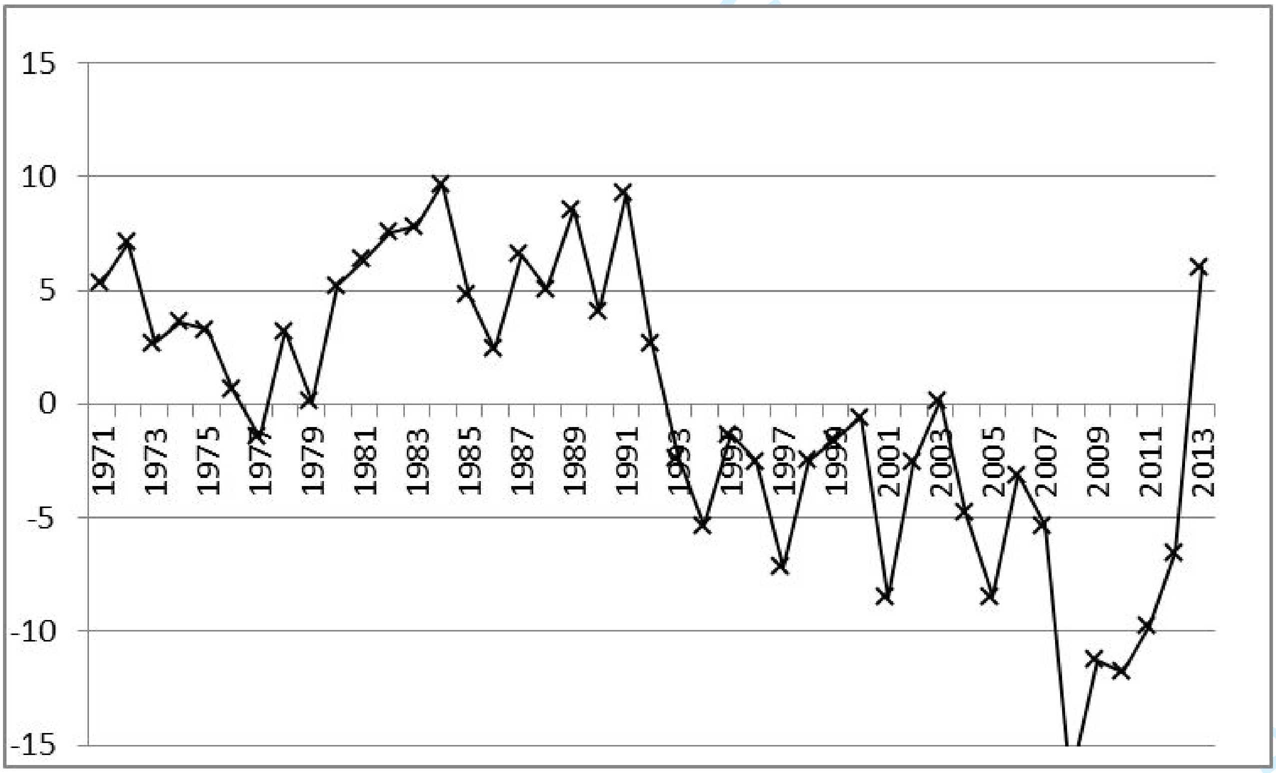
However, when data are disaggregated and distributed on subsectors, it becomes evident that not all subsectors develops poorly at all times. Figures 4, 5 and 6 below show annual labour productivity growth rates in the three subsectors: construction of new buildings, civil engineering, and professional maintenance and repair of buildings. From the diagrams, it is evident that productivity developed very differently in the three subsectors. Particularly over the last twenty years, annual productivity development has been positive only in construction of new buildings whereas maintenance and repair work displays a nearly complete lack of positive productivity change while civil engineering displays an unstable and, in some years, substantially negative productivity growth.

Figure 4. Labour productivity, construction of new buildings 1971-2013. Annual growth rate, 2010 prices, 5-year average, %



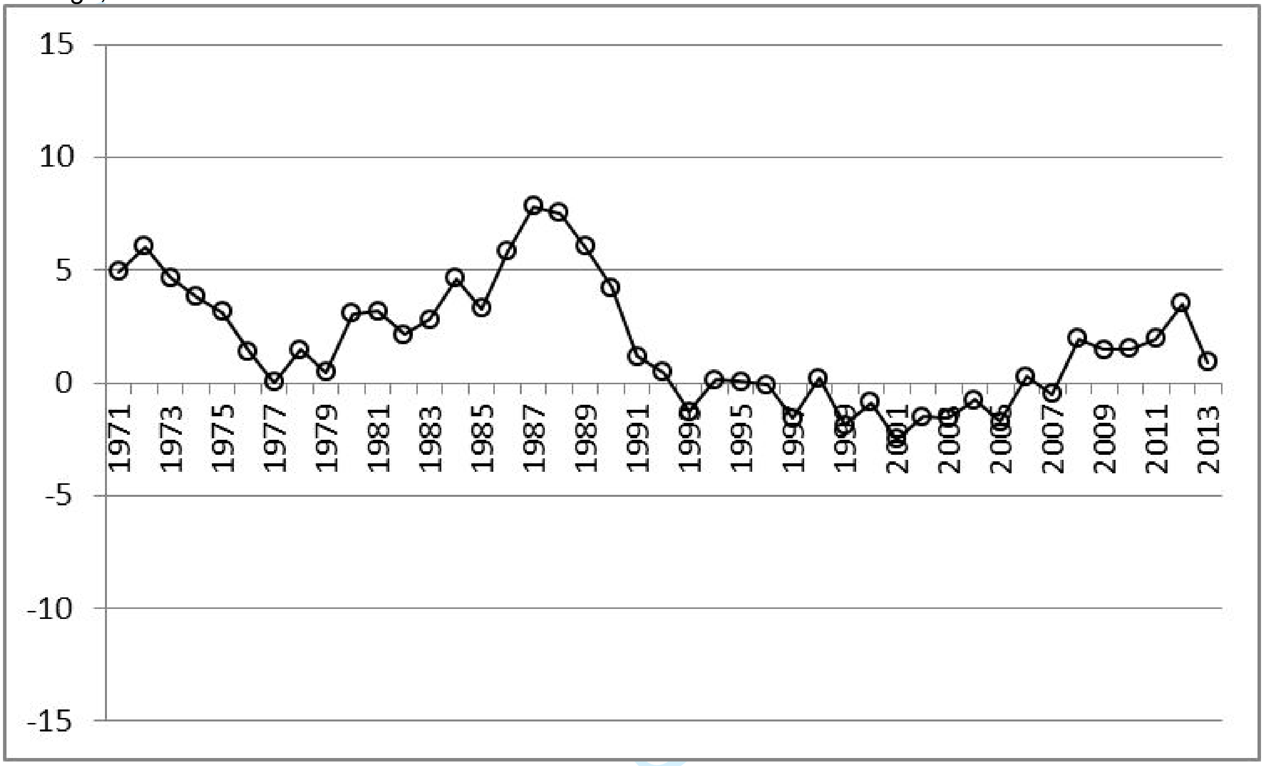
Source: Statistics Denmark (2018). National Accounts, Table NP3

Figure 5. Labour productivity, civil engineering 1971-2013. Annual growth rate, 2010 prices, 5-year average, %



Source: Statistics Denmark (2018). National Accounts, Table NP3

Figure 6. Labour productivity, maintenance and repair 1971-2013. Annual growth rate, 2010 prices, 5-year average, %



Source: Statistics Denmark (2018). National Accounts, Table NP3

While it is challenging to achieve stable and positive productivity growth in contemporary civil engineering and maintenance and repair sectors, this is not necessarily the case for construction of new buildings. Moreover, civil engineering as well as maintenance and repair seem to be constantly challenged by low or even negative productivity development no matter the macroeconomic environment. In contrast, positive annual productivity growth in new building construction seems to be linked to general economic growth, most notably in the mid-1990s and mid-2000s, even if the more specific character of the relation is vague.

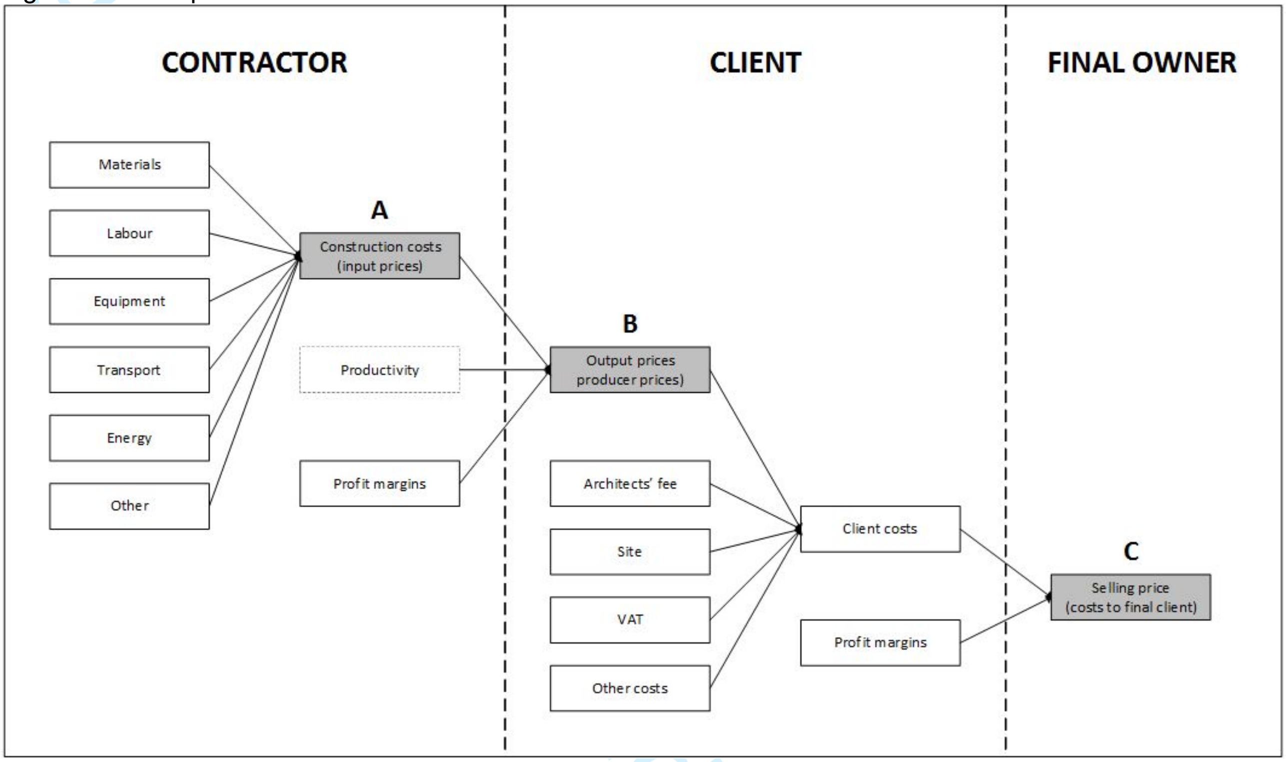
CHANGES IN PRODUCT CHARACTERISTICS: A NOVEL PERFORMANCE-BASED METHODOLOGY

This chapter describes and demonstrates a novel performance-based methodology for addressing changes in the characteristics of the products in a longitudinally perspective, which can potentially provide a better understanding of changes in productivity. It builds on data from Nielsen et al. (2010), while the method has been modified and extended for this paper. The method entails four steps:

1. Identify changes in input factors over time
2. Compare output prices over time by projection to reference year
3. Identify changes in characteristics of the product over time
4. Price and compare the changes of the characteristics of the product

Following the approach of statistical offices to input/output studies, a simplified value chain is established as a starting point. The value chain consists of three main actors: contractor, client and final owner. Figure 7 provides an overview of the conceptual frame and the associated terms of construction costs (marked with A), output prices (marked with B) and selling prices (marked with C).

Figure 7. Conceptual frame



Source: Adapted after Danmarks Statistik (2010: 100).

Step 1. Identify changes in input factors over a 50-year time period

The first step is to identify changes of input factors on client costs distributed on main cost groups. Especially the input of consultancy is important as an increase or decrease in input from consultancy may reflect an improvement of the characteristics of the product. Hence, consultancy costs may serve as a proxy for improvements of for example the architectural quality of the building as a product or reflect a larger amount of knowledge embedded in the product in relation to e.g. control and management systems.

The distribution of client costs on various cost groups like construction costs, consultancy fees, site purchase etc. are readily available for the Danish social housing sector as these are regularly registered as part of the public control of subsidies for social housing. Table 1 shows the relative distribution of costs to the final client of the four cases distributed on four main cost groups: building land, contractors, consultants and other costs (e.g. cost for connecting to the public utilities and sewage systems).

Table 1. Main cost groups' share of total costs, %

	Herman Bangs Plads	Sjælør Boulevard	Emaljehaven	Havnestaden	
				Scheme B	Scheme C
Building land	10.6	12.1	19.9	13.0	14.5
Contractors	67.9	59.7	60.8	67.7	78.5
Consultants	4.8	6.1	6.1	6.5	1.3
Other costs	16.7	22.0	13.2	12.8	5.6

Source: Adapted after Nielsen et al. (2010: 21).

It appears that no significant changes in consultancy costs have occurred over a 50-year period in the relative distribution of main cost groups. Hence, this indicates that significant improvements with regard to the characteristics of the product have either not been achieved or have indeed been achieved with the same resource effort as consultants have become more effective in delivering their services.

While changes in input from consultancy may in itself reflect an improvement in productivity on behalf of consultancies, more importantly due note should be taken with regard to the input from consultancy as these may depend on the actual organisational layout of the building project. Consultancy costs may for example be included in the construction costs of the contractor as an input either as a subcontracting cost in case of a design-build contract or as an internal cost due to the establishment of internal design and engineering departments in a contractor firm.

This effect is clearly demonstrated in the case of Havnestaden where the construction costs (output prices) change rather dramatically between the registration in Scheme B (the tendering point of time) and Scheme C (the conclusion of the project and final accounts). However, the significant change in distribution between various cost groups essentially reflects a change in the organisational setup from design-bid-build to design-build, in which the consultancy costs and other costs becomes part of the construction costs as the contractor takes over the engineering consultancy work as either an in-house service or as a subcontracted service.

Finally, it should be noted that the relatively stable share of consultancy costs does not in itself imply that input from consultancy remains stable, as the denominator being the total costs to the final client may have increased in the same period. This is actually the case as will become evident in the next section.

Step 2. Compare output prices over time by projection to reference year

The second step is to make prices comparable over time without taking into account any changes in the characteristics of the product. This is done by projecting all prices to the same base or reference year. It was decided to base a price comparison on prices adjusted according to the consumer price index for 2005 (Danmarks Statistik, 2018). Table 2 shows the contractor's construction costs (as output or producer prices) per square meter in actual prices, the relative index (1.00 for 2005 prices), the construction costs converted to 2005 prices, and costs in 2005 prices as a percentage of the costs in 2005 for Emaljehaven.

Table 2. Contractor's construction (output) prices per square meter in Danish Kroner (DKK)

	Herman Bangs Plads (1957)	**Sjælør Boulevard** (1972)	**Emaljehaven (2005)**	**Havnestaden (2005)**	
				Scheme B	Scheme C
Costs as-built (DKK)	378	907	11,518	12,552	14,393
Cost index as year 2005 / construction year	11.49	5.47	1.00	1.00	1.00
Costs converted to 2005 prices (DKK)	4,343	4,963	11,518	12,552	14,393
Costs relative to 2005 prices (%)	38	43	100	109	125

Source: Adapted after Nielsen et al. (2010: 20).

As indicated in Table 2, the contractor's construction costs have more than doubled and close to tripled in the 50-year period studied. This is a remarkable observation, which calls for an explanation. As markets usually do not allow entire industrial sectors to seize a growing profit, other factors like changes in the characteristics of the product must be at play to justify such a dramatic increase in costs.

Step 3. Identify changes in the characteristics of the product over time
The third step is to examine the changes in the characteristics of the product over time in a more detailed manner. The four cases were compared on a number of parameters in order to identify changes that could motivate a correction in prices as presented in the previous step. Focus centred especially on improvements in technical performance, which called for increased use of resources during construction. Table 3 shows the technical data of the four cases.

Table 3. Key technical performance parameters for the four cases

	Unit	Herman Bangs Plads	Sjælør Boulevard	Emaljehaven	Havnestaden
Construction year		1957	1970	2005	2005
Gross floor area	m^2	1,273	47,344	5,800	2,761
Net area of apartment	m^2	68.2	70.9	67	73
Gross area of apartment, excl. balcony and staircase	m^2	84	81.9	78.3	83.2
Gross area of apartment	m^2	90.2	90	87,3	94.3
Floor height	m	2.94	2.90	2.90	2.87
Length of façade of an apartment	m	16.75	13	13.5	13.3
Building width	m	10	15.41	11.88	11.87
Area of façade, excl. windows	m^2	36.2	22.3	29.6	14.9
Area of window sill	m^2	3.6	0	0	0
Area of windows	m^2	13	15.4	9.6	23.2
Heat loss per m^2 of facade	W/K/ m^2	1.58	1.62	0.62	0.97
Heat loss through facades	W/K	77.7	61.2	24.1	37.1
- Per net m^2 of apartment	W/K/ m^2	1.14	0.86	0.36	0.51
Kitchen, area	m^2	7.3	10.4	7.8	17.4
- Length of table top incl. sink and stove	m	2.6	3.4	2.4*	3.6
- Area of tiles	m^2	1.2	0	0.8	0
Bathroom, area	m^2	3.1	3.19	4.1	4.9
- Area of tiles	m^2	11.6	11.3	4.8	6.4
Installations					
- Mechanical ventilation		No	Yes	Yes	Yes
- Number of sockets		14	20	16	14
- Preparations for lamps		9	11	12	20
- Sockets for washing machines		0	1	2	2
- Sockets for phone, TV and IT		None	Phone and TV	All	All
Balcony, area	m^2	0	4.5	5	8.1
Elevator		No	No	Yes	Yes

Source: Adapted after Nielsen et al. (2010: 16).

Table 3 lists a number of notable observations regarding the technical performance of social housing over the 50-year period covering craft-based production, industrial production and contemporary production of social housing. First, the size of projects vary significantly. Second, the observations show a number of improvements in the technical performance of building for example with regard to energy performance and the introduction of mechanical ventilation and elevators in multi-storey buildings. Third, the observations show some reductions in technical performance over time for example a reduced surface area with tiles in bathrooms. Fourth, the observations illustrate that some parameters remain relatively stable over time like the floor height.

Step 4. Pricing and comparing the changes of the product

As presented above in the third step, a number of changes over time were identified. Based on this analysis and other observations in the apartments, estimates of the monetary value of these changes are presented in the following. Changes in characteristics of the product, which were considered to represent an increased value, are listed in Table 4.

Table 4. Most important changes in performance over 50 years and their monetary value

	Changed performance	Quantity per apartment	Value (2005-DKK) per m^2 of apartment
1	Better thermal insulation of facades	About 30 m^2 of wall with a reduction of heat loss to one third	300
2	Larger bathrooms	3 to 4 m^2	100
3	Larger balconies	2 to 8 m^2	200 to 300
4	Elevator	From 0 to 1 per staircase	400 to 600
5	Installations	Ventilation	100
		More sockets for lamps	-
		Socket for washing machines	5
		Socket for phone, TV and IT	50
6	More appliances	Fridge, freezer, dishwasher and washing machine	100
7	Better building physics solutions	Membranes, fire, sound	100 to 200
	Sum: Items 1 to 7		**1.355 to 1.755**
	Sum: Items 1 to 7 in relation to the construction costs of Emaljehaven (11,518 DKK/m^2)		**12 to 15%**

Source: Adapted after Nielsen et al. (2010: 18).

The increased costs for higher technical performance as listed from items 1 to 7 in Table 4 was estimated by experienced contractors and indicated that an increased price of 13-15% of the construction costs can be expected. If the increased degree of industrial finish is also considered, about 20% may be a fair estimate of the total monetary value of the increased performance of technical solutions during the 50-year period covered by the investigation.

DISCUSSION

The building and construction sector is repeatedly criticised for low productivity, but the nature of the productivity problem in building and construction is not as simple as it looks. Although national statistics may paint a bleak picture of a poorly performing industry, the very first problem to address is whether these statistics provide an accurate picture of the productivity development in the building and construction sector. Indeed, a major problem is that the statistical data provided are not trustworthy as they rely on deflators that do not represent the output of building and construction adequately. This underlines the need to develop more appropriate measurements of construction output that are capable of addressing changes in the quantity of the products, changes in the composition of the aggregate and changes in the characteristics of products. The suggested four-step approach seems to be a promising way of disentangling the problem of measuring construction productivity, but it also pointed at two associated problems related to the interpretation of results as well as the method in itself.

The hypothesis of this study was that an improved measurement of both output prices and performance of actual building projects would show a far more positive productivity development compared to the national input-output statistics. However, the most remarkable result found in this study was that output prices adjusted according to the consumer price index had nearly tripled over a period of 50 years. This is in stark contrast to results obtained by other methods. A change in input factors cannot explain this dramatic increase. In the four cases, no dramatic change in the distribution of main cost groups was seen over the period of 50 years in spite of the industrialisation that had taken place during that period. This indicates a relatively high stability over time in input factors, which is in contrast to the result of the many input-output studies across nations in which consultant´s services expanded significantly. With regard to performance, the expectation was that it had improved and generated substantially higher value of dwellings. Hence, the study confirmed that technical performance improvements have emerged that are not accounted for in the national input-output statistics.

However, only a relatively small increase in construction costs, namely some 20%, may be justified by higher performance. The significance of these observations are potentially grave. If the results can be trusted, they imply that the development of construction productivity is even worse than input-output statistics based on the national accounts would suggest. Hence, it would seem as if Danish social housing construction has experienced a long-term gradual degradation of the relationship between costs and performance making social housing more and more expensive without delivering a corresponding increase in performance. Consequently, this points at the need for strong and urgent measures to counteract this unfortunate development.

On the other hand, there are also methodological reasons to pause. Since only a small proportion of the increase in output prices can be explained by increases in technical performance, it should be further investigated if the sector has delivered increased services of other types. This includes a closer focus on a higher degree of industrial finish, more diversity in technical solutions, and smaller scale buildings with extensive variation in architecture. If costs related to these items explain a significant part of the increase in output prices, it might be a topic for a wider discussion if all consumers are willing to pay that price. Another important topic is the influence of increased public requirements such as waste management, labour standards, climate adaptation, etc.

The study has demonstrated that – at least some – technical performance improvements can be identified and capitalised using the suggested four-step approach. The longitudinal four-step methodology for measuring construction output as performances offers a novel view on productivity development over time compared to national input-output studies and more traditional micro-level studies focused on cross-sectional comparisons of e.g. construction technologies. It deserves further development and application aiming to close the gap between results obtained by different methods and establishing a deeper understanding of the mechanisms behind productivity development in construction. Further development of the method should include at least two items. First, it should be discussed if the consumer price index is the best index to use for the projection of output prices. For the inhabitants of dwellings, it is certainly relevant, but seen from the construction sector point of view there might be better alternatives. Second, a closer look at changes in input factors seems to be required as especially labour costs constitute a significant proportion of input to construction.

Although all cases were taken from social housing, the results suggest they would be valid for the residential building sector in general, since the same companies are active in the entire sector. While the results in Table 1 show that the distribution of main cost groups have not changed significantly over the 50 years, it shows a clear difference when compared with the design-build project of Havnestaden (Scheme C). This appears to be explained by the transfer of consultancy tasks and responsibilities to the design-build contractor. Hence, it indicates the need to include information on contract forms when measuring output prices in order to make reliable input-output statistics in the national accounts.

In addition, the study has demonstrated that – at least some – technical performance improvements can be identified and capitalised using the suggested four-step approach. However, additional work is generally required in order to capitalise future savings that are the result of up-front construction investments, which may drive up output prices on the prospect of future gains. For example this study explained part of the increase in output prices by increased costs of energy-saving measures. Similarly, improved design, choice of technical solutions, etc. may reduce cleaning costs during operation, which tends to be at least equally important as a cost driver during operation (Haugbølle & Raffnsøe, 2018). Ironically, these savings made during the operational life of a building are not included in productivity measurements or in input-output studies.

CONCLUSION

This paper set out to bridge the gap between macro-level studies and micro-level studies on construction productivity by adopting a longitudinal approach to measurement of changes in construction output at micro-level, which addresses both the negligence of product characteristics in macro-level studies and the negligence of change over time in micro-level studies. Indeed, a major problem is that the statistical data provided are not trustworthy as they rely on deflators that do not represent the output of building and construction adequately. Hence, the ambition was to improve our understanding of construction output – being the numerator in construction productivity calculations – by focusing on changes in quantity of the products, product characteristics and composition of the aggregate rather than as changes in price.

First, this study has demonstrated how the composition of the aggregate measurement of building and construction output has changed in Denmark. Although civil engineering exhibits a slight growth, the role of civil engineering is diminishing relative to construction of new buildings and professional maintenance and repair of existing buildings. Particularly the role of maintenance and repair work seems to have followed a stable although slow growth, whereas the subsector construction of new buildings is more exposed to changes in economic cycles.

Second, this study has developed a novel four-step method for longitudinally measuring changes in the characteristics of the products of construction, in this case social housing. This novel method to adjust construction output with the help of performance metrics improve our understanding of the role that changes in the characteristics of the product may have for the measurement of construction output. The method for measuring the changes in characteristics of construction output was tested on four exemplary social housing projects covering a 50-year period. The findings indicate that while construction prices have increased almost three-fold over the past 50 years, the monetary value of improved technical performance can only explain approximately 20% of this increase. Additional performance parameters like small-scale architecture may also play a role as cost driver, but further studies are required to identify and capitalise these parameters.

Although more work is still required in order to fully understand and appreciate the true nature of construction, these insights may in a long-term perspective prove useful in adjusting the numerator in the calculation of productivity in construction. This may in turn assist in designing more effective and evidence-based policies for improving construction productivity rather than relying on unsubstantiated or outright erroneous perceptions.

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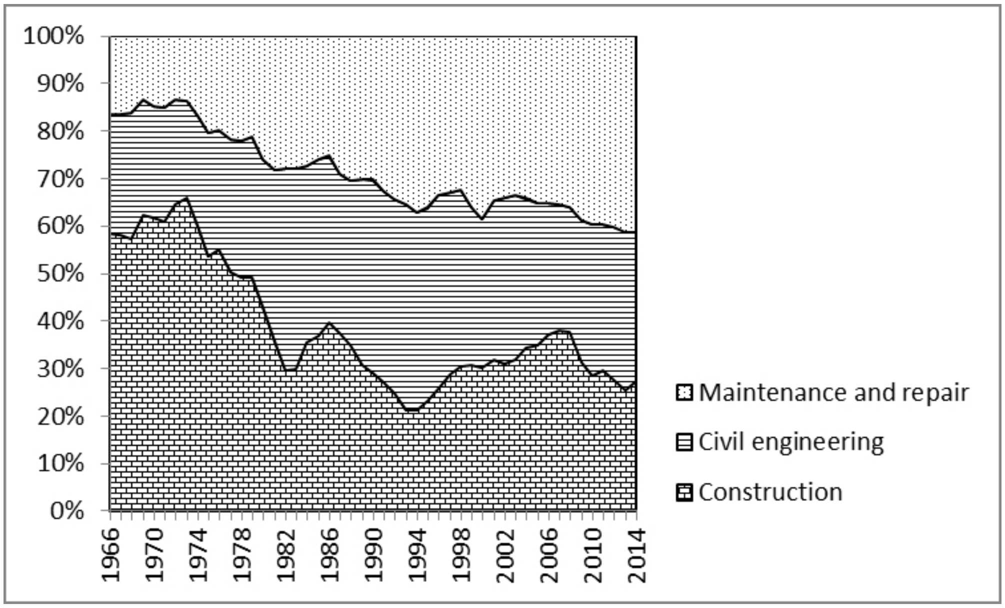

Figure 2. Distribution of output value, construction subsectors 1966-2014. Fixed prices (2010), %

127x76mm (150 x 150 DPI)

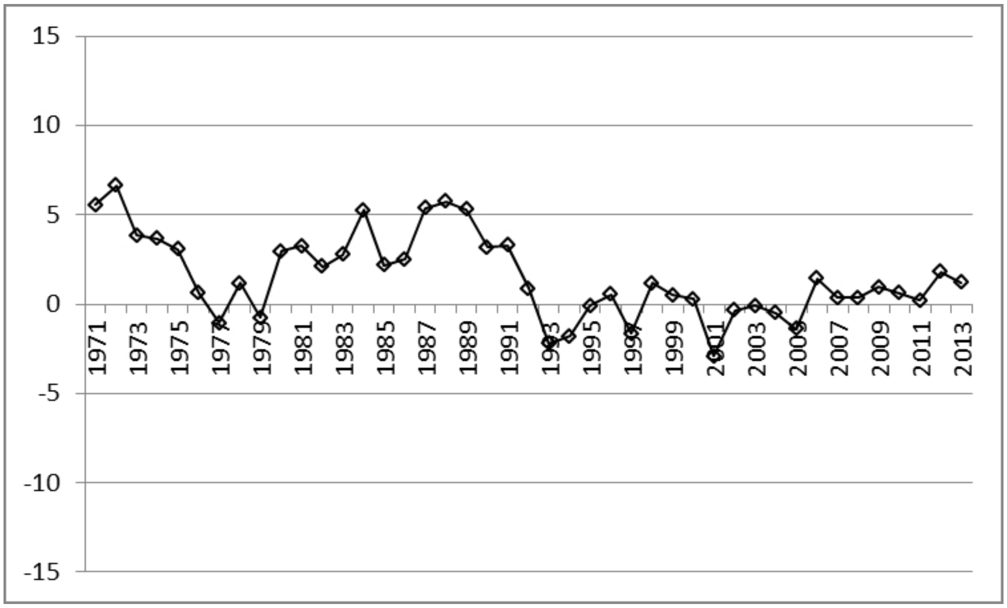

Figure 3. Labour productivity, all construction sectors 1971-2013. Annual growth rate, 2010 prices, 5-year average, %

127x76mm (150 x 150 DPI)

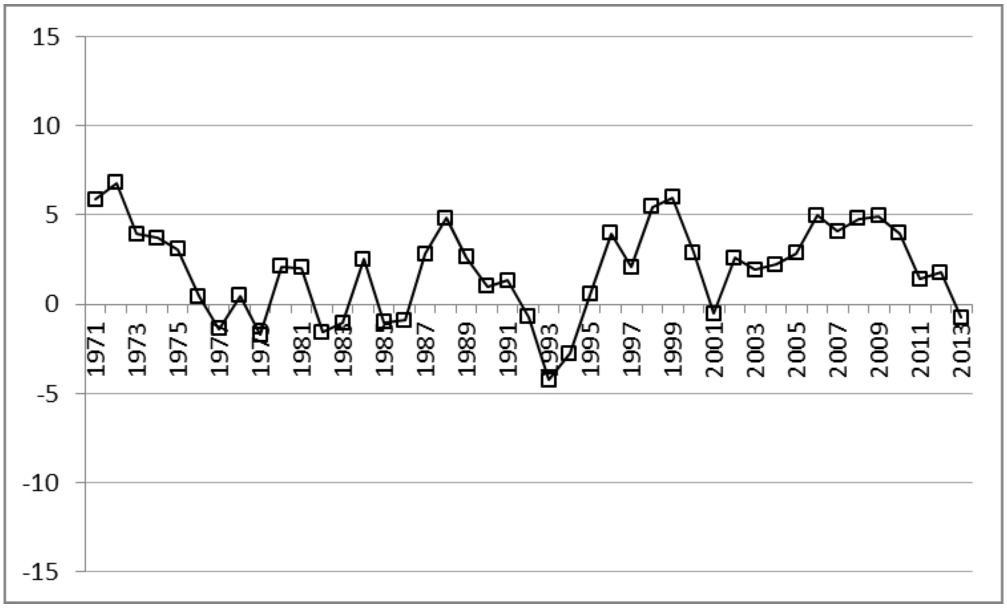

Figure 4. Labour productivity, construction of new buildings 1971-2013. Annual growth rate, 2010 prices, 5-year average, %

127x76mm (150 x 150 DPI)

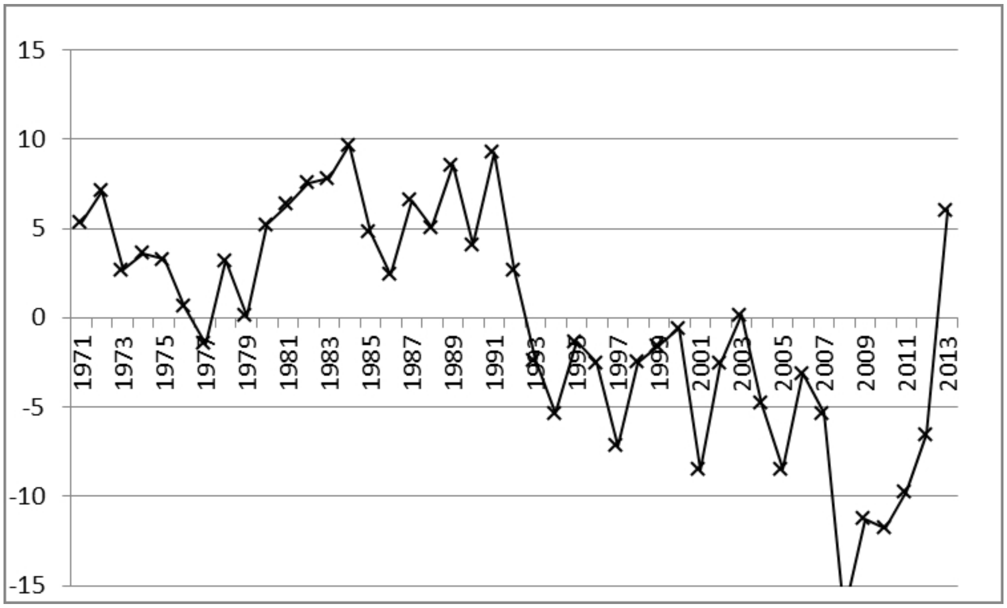

Figure 5. Labour productivity, civil engineering 1971-2013. Annual growth rate, 2010 prices, 5-year average, %

127x76mm (150 x 150 DPI)

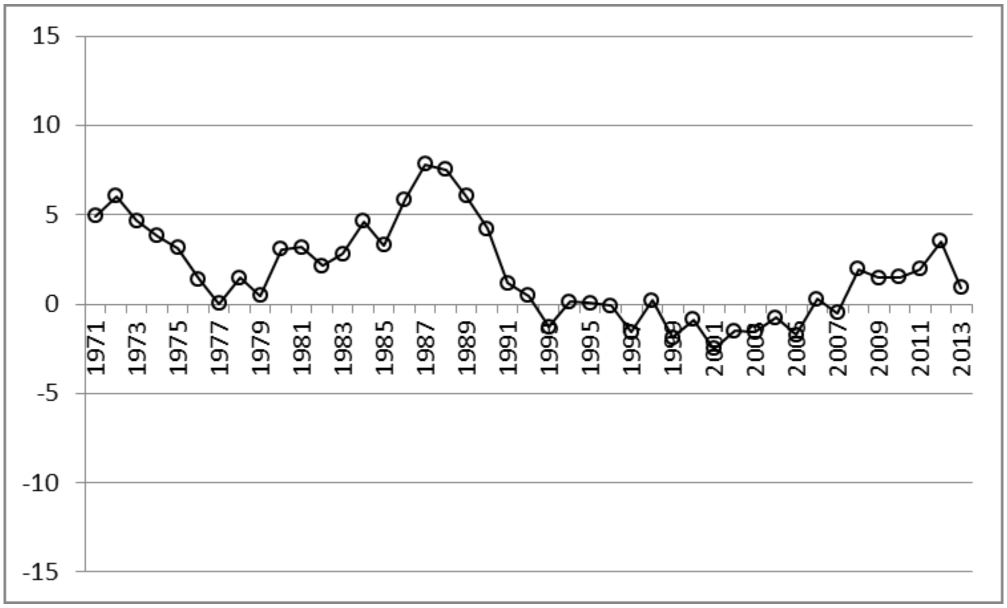

Figure 6. Labour productivity, maintenance and repair 1971-2013. Annual growth rate, 2010 prices, 5-year average, %

127x76mm (150 x 150 DPI)

	Herman Bangs Plads	Sjælør Boulevard	Emaljehaven	Havnestaden	
				Scheme B	Scheme C
Building land	10.6	12.1	19.9	13.0	14.5
Contractors	67.9	59.7	60.8	67.7	78.5
Consultants	4.8	6.1	6.1	6.5	1.3
Other costs	16.7	22.0	13.2	12.8	5.6

	Herman Bangs Plads (1957)	Sjælør Boulevard (1972)	Emaljehaven (2005)	Havnestaden (2005)	
				Scheme B	Scheme C
Costs as-built (DKK)	378	907	11,518	12,552	14,393
Cost index as year 2005 / construction year	11.49	5.47	1.00	1.00	1.00
Costs converted to 2005 prices (DKK)	4,343	4,963	11,518	12,552	14,393
Costs relative to 2005 prices (%)	38	43	100	109	125

	Unit	Herman Bangs Plads	Sjælør Boulevard	Emaljehaven	Havnestaden
Construction year		1957	1970	2005	2005
Gross floor area	m^2	1,273	47,344	5,800	2,761
Net area of apartment	m^2	68.2	70.9	67	73
Gross area of apartment, excl. balcony and staircase	m^2	84	81.9	78.3	83.2
Gross area of apartment	m^2	90.2	90	87,3	94.3
Floor height	m	2.94	2.90	2.90	2.87
Length of façade of an apartment	m	16.75	13	13.5	13.3
Building width	m	10	15.41	11.88	11.87
Area of façade, excl. windows	m^2	36.2	22.3	29.6	14.9
Area of window sill	m^2	3.6	0	0	0
Area of windows	m^2	13	15.4	9.6	23.2
Heat loss per m^2 of facade	W/K/ m^2	1.58	1.62	0.62	0.97
Heat loss through facades	W/K	77.7	61.2	24.1	37.1
- Per net m^2 of apartment	W/K/ m^2	1.14	0.86	0.36	0.51
Kitchen, area	m^2	7.3	10.4	7.8	17.4
- Length of table top incl. sink and stove	m	2.6	3.4	2.4*	3.6
- Area of tiles	m^2	1.2	0	0.8	0
Bathroom, area	m^2	3.1	3.19	4.1	4.9
- Area of tiles	m^2	11.6	11.3	4.8	6.4
Installations					
- Mechanical ventilation		No	yes	yes	yes
- Number of sockets		14	20	16	14
- Preparations for lamps		9	11	12	20
- Sockets for washing machines		0	1	2	2
- Sockets for phone, TV and IT		none	Phone and TV	All	All
Balcony, area	m^2	0	4.5	5	8.1
Elevator		no	No	Yes	Yes

	Changed performance	Quantity per apartment	Value (2005-DKK) per m² of apartment
1	Better thermal insulation of facades	About 30 m² of wall with a reduction of heat loss to one third	300
2	Larger bathrooms	3 to 4 m²	100
3	Larger balconies	2 to 8 m²	200 to 300
4	Elevator	From 0 to 1 per staircase	400 to 600
5	Installations	Ventilation	100
		More sockets for lamps	
		Socket for washing machines	5
		Socket for phone, TV and IT	50
6	More appliances	Fridge, freezer, dishwasher and washing machine	100
7	Better building physics solutions	Membranes, fire, sound	100 to 200
	Sum: Items 1 to 7		**1.355 to 1.755**
	Sum: Items 1 to 7 in relation to the construction costs of Emaljehaven (11,518 DKK/m²)		**12 to 15%**