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# Future Directions for Building Services Technologies in Denmark

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**Abstract.** The hypothesis of this paper is that industrial transformation in the Danish construction sector needs in the future to focus on integrating building services technologies into the buildings. This can be illustrated by analysing historical developments in building services usage, exploring design strategies for the effective integration of building services, and by developing new industrialised solutions for building services. The paper is based on the current Danish situation, and is based on linking research on building services, user needs, building design and new industrial processes.

**Keywords:** Building services, Intelligent buildings, Integrated building design, Industrialisation.

## 1 Introduction

Over the last 100 years there has been a large increase in the extent of these building services, with Nordic data showing a large growth in building services' share of total office construction costs. Today's buildings need many different building services to create the necessary functionality that users demand, and the growing importance of building services show perceptions of buildings are changing:

- *From static and passive constructions* providing the basic functions of climatic tempering.
- *To dynamic and adaptable functional spaces*, where intelligent building services are the driving force in providing for changing user demands.

Despite the growing importance of building services, they have not been a central focus for the construction sector's industrialisation. The largest productivity gains from industrialisation can therefore be achieved by focusing on building services because they are a growing proportion of total construction costs, and they represent the least industrialised part of the construction process. The hypothesis of this paper is therefore that industrial transformation in the Danish construction sector needs to focus on integrating building services technologies in the buildings of the future. This paper is based on current Danish research and practice into building services, user needs and industrialisation, and has the following objectives:

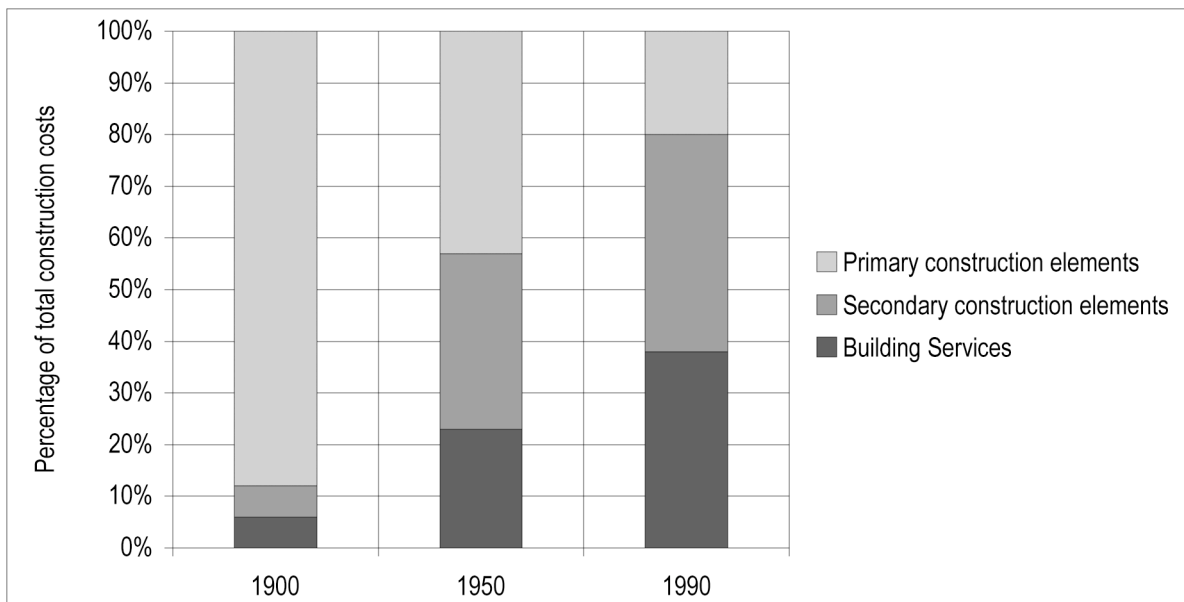
- To analyse the historical development of building services provision in Denmark.
- To understand in a broader perspective how building services provision can be linked to processes of social and technological change in satisfying user needs.

- To explore strategic design principles for the integration of building services technologies into buildings, so that changing user demands can be incorporated into the building design and procurement process.
- To analyse how building services technologies can be modularised and prefabricated, so that greater value is created for clients and users by reducing construction costs/time and improving construction quality.

## 2 Historical Development of Building Services Provision in Denmark

Today's buildings need many different building services to create the required functionality that building users demand, and over the last 100 years there has been a considerable increase in the numbers and extent of these building services [1]. This transformation is also visible in Denmark and the other Nordic countries:

- Nordic data relating to the construction costs of offices show that the building services' share of the total costs has risen from 5% in 1900, to 23% in 1950, and further to 40% in 1990 [2], as shown in figure 1. Comparable data for several countries in North America and Europe show similar trends [3].
- Danish data relating to time usage on construction sites for housing projects shows that time consumption used on the building services has grown from 6 % of the total construction time in 1951 to 20 % in 1994 [4], [5].



**Fig. 1.** Construction costs in relation to different construction elements for Nordic office buildings from 1900 to 1990.

The historical development of building services in Denmark can be divided into three phases [6]. During the period from the 1850's to the 1940's, the first foundations for the industrial society were laid, and urban areas experienced a very large growth. The basis for these transformations was the introduction of the first modern ideas relating to public health [7]. In a Danish context, the first building services in the form fresh water supplies and wastewater disposal systems were provided for housing areas in the larger urban centres with the aim of improving the growing population's health. In terms of building design, these changes meant that new functions were provided for in buildings, and that this resulted in a design and construction rationalisation, where kitchen and bathroom functions were placed close to each other to minimise the extent of vertical ducts to water supply and wastewater drainage in housing [8].

During the period from the 1940's to the 1980's, rapidly advancing technological developments, such as mechanical ventilation, air conditioning and artificial lighting, allowed the provision of higher levels of comfort in buildings that were independent of the building fabric's traditional climatic regulation. These technological transformations led to the development of the new building types, characterised by the international style of modern architecture [1], where very deep buildings became possible, and very light curtain wall façade systems with large glazing areas became the norm, allowing for rationalised construction processes. In the nordic countries, the development of central heating and district heating systems meant that fireplaces became functionally obsolete, and this in turn meant that independent ventilation systems became necessary [9]. These ventilation systems were typically placed in conjunction with the already existing vertical ducts for water supply.

From the 1980's and onwards, developments within the field of information technology have led to a vast and continuing growth in the provision of so-called intelligent building services [10]. This development covers many aspects:

- *Knowledge*: The extensive use of IT has allowed the growth of modern knowledge-based businesses, where 'New Ways of Working', innovative and creative working patterns supported by adaptable workspaces, are a competitive prerequisite and a driving force in modern business models [11].
- *Entertainment*: The growth in IT, multimedia and communication technologies in today's households, including the development of so-called smart-house systems [12]. These technologies are also responsible for the rapid growth in household electrical consumption.
- *Control*: The growth of intelligent control systems in all buildings, especially related to facilities management and the environmental control of energy use, indoor climate, etc. [13]. These systems typically add a new layer of intelligent control on the top of existing building services.

### **3 Processes of Change and Building Services Provision**

Modern society can be characterised by continuing and fluid processes of social and economic change [14], and these processes naturally affect the perception and use of

buildings. For offices, IT and the knowledge economy mean that dynamic business processes demand that both employees' and the building's ability to adapt over time are seen as innovative competitive prerequisites in their own right [15]. For housing, both lifestyle and demographic changes are affecting the way that housing is perceived [16], and this is reflected in new housing developments in Copenhagen such as the ON:HOUSE project, which is now being innovatively branded in relation to the internet and multimedia lifestyles.

An important aspect relating to the development of building services is their role in providing the new levels of intelligent functionality which building users' demand [6]. This can be in satisfying user requirements in relation to both improved comfort control and newer IT and multimedia services. Another important aspect is how services become 'layered' in the transition from traditional low technology services to newer intelligent services with a high technology content. It can for example be argued that building services do not disappear, but low technology solutions become replaced or augmented by newer intelligent solutions [13].

With building services being responsible for a large proportion of buildings' functionality, it is now possible to see a transformation in how buildings are used and perceived [17]:

- *From the historical view of buildings as static and passive constructions*, where concrete and brickwork were responsible for basic functions relating to shelter and climate tempering.
- *To a newly developing view of buildings as dynamic and adaptable functional spaces*, where intelligent building services are the driving force in meeting users' changing functional requirements over time.

## **4 Strategies for the Integration of Building Services Technologies**

It is clear that the processes of social, technological and economic change described above, together with the increasing use of new building services technologies, puts focus on the design and procurement of buildings. Principles for building services design and distribution need therefore to be integrated with principles for managing building usage and change early in the building design and procurement process [10].

This integration can be highlighted by looking at the historical development of office design from the 1950's to today [6]. In the first office buildings of the Modern Age, as described above, it was very typical for the vertical services ducts to be placed in connection with toilet and kitchen facilities in the service zones on each floor, since it was in these areas that the majority of the traditional building services were located. This decision can be seen rational in terms of minimising construction costs.

However, in the following years, because of the functional and technological transformations ushered in by the Intelligent Age, there has been an explosive growth in the extent of building services located in the office zones. This growth includes new IT, communications and data systems, and extensive ventilation and cooling systems to control the indoor climate because of the growth in electrical and electronic equipment found in these office areas. However, this transformation of building services requirements has not resulted

in fundamental changes in design strategies for building services provision. The vertical ducts have been enlarged and are still centralised in the service zones, whilst they are now accompanied by large horizontal ducts to ventilation, which have become very deep because of the large floor areas that are serviced and the large air volumes to be transported. It is now typical for many new nordic office developments that between 25 and 33 % of the total floor to floor height is used to horizontal service ducts hidden behind suspended ceilings [2].

As an alternative to the traditional centralised building services systems, newer nordic research has pointed towards the advantages of utilising a decentralised distribution of the building services [2], [6]. The traditional centralisation of the office's vertical ducts may mean increased construction costs as a consequence of the extensive horizontal ductways and the increased storey height. It may also result in a reduced capacity for change and higher operating costs since the changes affect the functionality of the whole system. In contrast, studies show that there may be many advantages attached to a decentralisation of the building services ducting when the objective is to create innovative and intelligent workplaces:

- The office of the future should have relatively large and open floor areas that permit 'New Ways of Working' with innovative work processes and changing functional requirements.
- It should be possible to partition off these large and open floor areas into smaller decentralised function zones providing improved possibilities for individual control in relation to the desired functional requirements.
- The building services can advantageously be ducted decentrally in the building facade, which will provide the best possibilities for creating uninterrupted continuous office spaces with several smaller function zones [6].

## **5 Industrialisation of Building Services Technologies in Denmark**

There has been very little research or development work relating to the industrialisation of building services in Denmark. This has its roots in the traditional nature of the Danish construction sector, where building services engineers and contractors typically become involved very late in the procurement process, despite the growing proportion of construction costs connected with building services. The building services sector has therefore never been in a situation to set the agenda for the construction sector's future development. However, a preliminary study [18] has shown that the industrialisation and prefabrication of building services in Denmark can reduce total construction costs and times whilst also improving the technical quality of buildings.

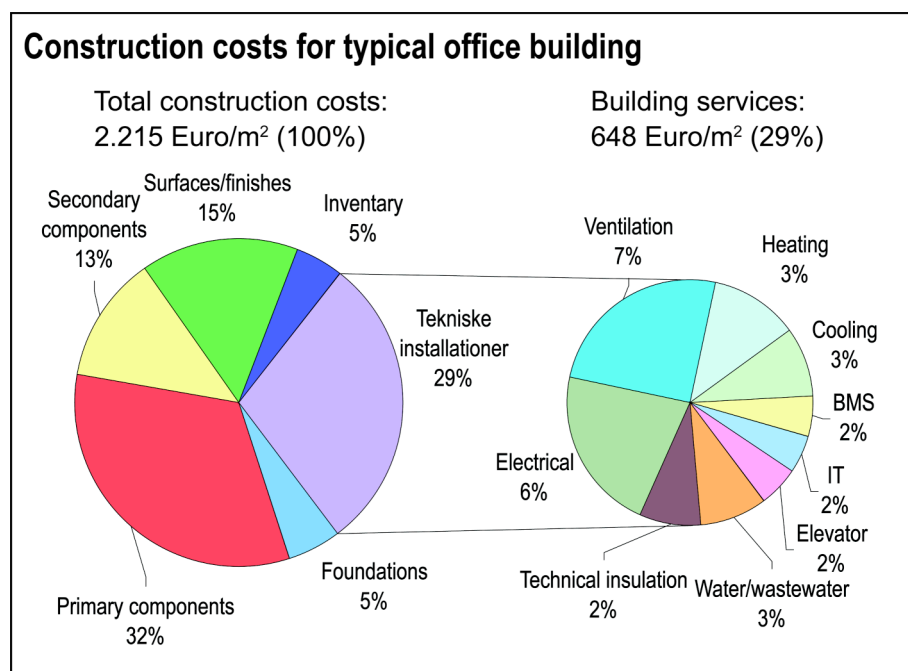
In Denmark the interaction between client, consultant and contractor has historical roots, where the organisation of the building industry has been dominated by economic demands relating to the historically relatively high construction costs of the loadbearing structure. A demand for greater efficiency has meant that the main efforts to industrialise the construction industry in Denmark have focused on the use of prefabricated concrete elements for buildings' loadbearing structures and facade elements [19]. This has resulted in reductions in construction costs and construction times for these elements. However, over time greater

functional demands to buildings have resulted in the growth of building services, which means that they have come to make up a far greater share of the total construction costs.

This dichotomy causes a number of conflicts between the traditional organisation of the building process and the new functional reality of buildings. The specification of building services is often decided at a late stage in procurement, which makes it difficult for installation to be carried out rationally. At the same time it can also be seen as paradoxical that building services, which already consist of prefabricated industrial (and often technology-advanced) products, are built into buildings in a handbuilt and craftsmanlike way because of tradition.

Studies from the UK have shown that considerable productivity increases in terms of reduced construction costs and construction times can be found by prefabricating building services [20], [21], [22]. In a Danish context, it can therefore be argued that the largest productivity gains from industrialisation can be achieved by focusing on building services because they are responsible for a growing proportion of total construction costs, and they represent the least industrialised part of the building process.

To explore the possibilities of industrialising building services provision in Denmark, a study has been carried out based on design and construction cost data for a typical office building. Construction cost data shows that this building has a construction price of 2.215 Euro/m<sup>2</sup> at 2005 prices [23], and that the building services account for about 30 % of this amount, as shown in figure 2.



**Fig. 2.** Construction costs for typical office.

The construction costs for the individual building service type can be further broken down with data relating to the weighting of the total costs in relation to the building services distribution hierarchy, that is from the main supply, through the plant room, vertical distribution and horizontal distribution, to the local services distribution in each room [2]. By taking each individual building service type that is supplied to the office space, and breaking the construction costs down in relation to the distribution hierarchy, it is possible to see where the targets proportion of the construction costs is placed, as shown in figure 3.

<b>Construction costs for building services and distribution to office spaces</b>								
	Building services type							Total
	Heating	Cooling	Tec. isol.	Vent	El	BMS	IT	
Construction cost Euro/m <sup>2</sup>	76	59	52	162	140	34	34	556
% of Total	3 %	3 %	2 %	7 %	6 %	2 %	2 %	25 %
% of Building services	14 %	11 %	9 %	29 %	25 %	6 %	6 %	100 %
Distribution hierarchy								Total
	Heating	Cooling	Tec. isol.	Vent	El	BMS	IT	
Ceiling: Local services	11	21	0	44	44	14	0	134
Horizontal distrib.	11	21	19	44	17	14	0	126
Floor: Local services	11	0	0	0	44	0	12	68
Horizontal distrib.	11	0	6	0	17	0	12	48
Vertical distribution	2	3	3	6	4	2	5	26
Plant room	23	15	21	65	10	4	2	140
Main supply	5	0	3	3	3	0	1	15
Total Euro/m <sup>2</sup>	76	59	52	162	140	34	34	556

**Fig. 3.** Construction costs for distribution hierarchy of building services for typical office.

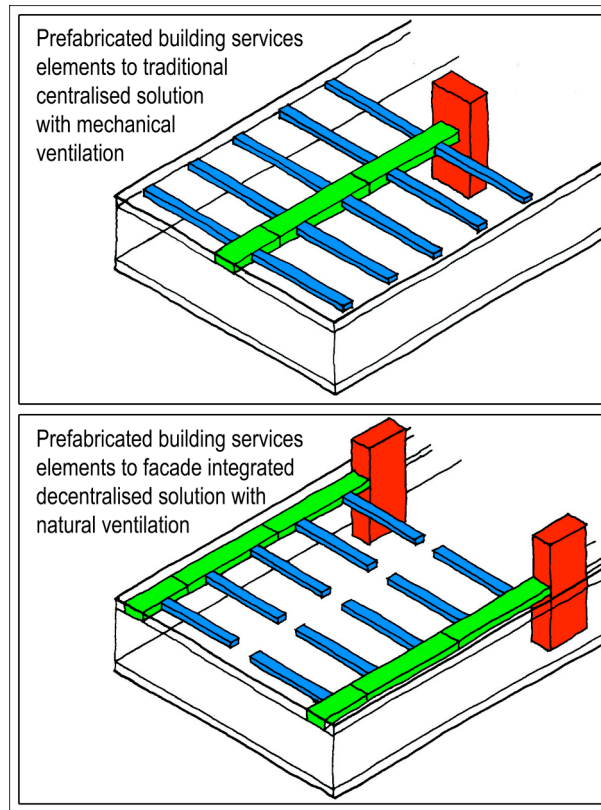
From figure 3 it can be seen that:

- The building services in the loft space, comprising the horizontal distribution (126 Euro/m<sup>2</sup>) and local services (134 Euro/m<sup>2</sup>), comprise the largest component of the building services construction costs at 260 Euro/m<sup>2</sup>.
- The plant room has the second highest construction cost at 140 Euro/m<sup>2</sup>.

It can therefore be argued that if building services are to be industrialised, then the largest cost and time related advantages are to be found by focussing attention on the building services with the largest construction costs, that is the horizontal distribution and local services located in the loft. These elements account for approximately half the total construction costs of the building services, which again equates to between 10 and 15 % of the office building's total construction costs.

The most effective solution is therefore to focus on developing prefabricated and modular elements to the distribution of all relevant building services types in the loft space of offices, as shown in figure 4. These modules can be used in conjunction with both traditional centralised solutions and the previously suggested decentralised, façade integrated solutions.





**Fig. 4.** Prefabricated building services elements to loft for typical office.

## 6 Conclusions

The hypothesis of this paper is that the Danish construction sector's industrial transformation needs to focus on integrating building services technologies in the buildings of the future. In a Danish context, the conclusions of the research work presented in this paper are as follows:

- An historical analysis shows there has been a large growth in the extent and costs of building services technologies over the last 100 years, and that this growth can be linked to changes in social and technological development. Comparable data for several countries in North America and Europe show similar trends.
- By linking changing user demands and growing building services provision with processes of social and technological change, it can be seen that perceptions of buildings are changing from static and passive constructions to dynamic and adaptable functional spaces. In this process, intelligent building services are becoming the driving force in meeting users' changing functional requirements over time.
- New strategic design principles can be developed to integrate and distribute the expanding range of building services into buildings, so that changing user demands for new intelligent

building services technologies can be incorporated into the building design and procurement process.

- An analysis of Danish office buildings has been used to show that it is best to focus attention on developing prefabricated and modularised building services elements for the horizontal distribution and local services located in the loft, so that greater value is created for clients and users by reducing construction and renewal costs/times, and improving construction quality.

The presented research draws together aspects relating to building services provision, changing user needs, building design and new industrial processes. It is clear that the growing building services provision is closely related to changing user needs and perceptions. From a Danish standpoint this points in the direction of new design and procurement processes which reflect these patterns, and a greater need for the use of prefabricated and modularised building services elements. This is because the largest productivity gains from industrialisation can be achieved by focusing on building services because they represent both a growing proportion of total construction costs, and the least industrialised part of the construction process.

Current processes of social and technological change also point towards the growing importance of IT and the knowledge economy. In terms of building services technologies, this implies that one can expect a growth in existing IT-related building services, and also the development of new types of building services technologies. This can span from energy saving low voltage electrical power distribution systems used to power the growing numbers of electronic appliances and equipment in buildings, to the use of pervasive computing technologies where IT and building surfaces melt together. These developments point towards the fact that the importance of building services technologies will continue to grow in the buildings of the future.

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