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Marsh, Rob

Published in:
Second International Conference World of Construction Project Management 2007

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Second International Conference World of Construction Project Management 2007
Prof. H.A.J. de Ridder, Prof. J.W.F. Wamelink (Eds.)

INTELLIGENCE, INTEGRATION & INDUSTRIALISATION FOR THE BUILDING SERVICES TECHNOLOGIES OF THE FUTURE

Dr. Rob Marsh*

* Danish Building Research Institute, Department for Building Design & Technology
Dr Neergaards Vej 15, DK-2970 Hoersholm, Denmark
e-mail: rom@sbi.dk

Abstract. *The hypothesis of this paper is that the construction sector's industrial transformation needs to focus on integrating building services technologies in the buildings of the future. This can be achieved by analysing developments in intelligent building services, exploring design strategies for effectively integrating building services, and by developing new industrialised solutions for building services technologies. This paper is based on current Danish research and practice, and it is based on linking research knowledge on building services to knowledge on user needs, building design and new industrial processes.*

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

1 INTRODUCTION

The hypothesis of this paper is that the construction sector's industrial transformation needs to focus on integrating building services technologies in the buildings of the future. Today's buildings need many different building services to create the necessary intelligent functionality that users demand. Over the last 100 years there has been a large increase in the extent of these building services, with Nordic data showing building services' share of office construction costs rising from 5% in 1900 to 40% in 1990. 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.

This paper is based on current Danish research and practice, and it is based on linking research knowledge on building services to knowledge on user needs, building design and new industrial processes. The paper has the following objectives:

- *Intelligence:* To analyse what is happening with changing user demands, changing building functionality and developments in intelligent building services, so that these new technologies' role in satisfying changing user needs can be promoted.

- *Integration:* To explore which strategic design principles can be used to integrate building services technologies into buildings, so that changing user demands for these technologies can be incorporated into building design and procurement.
- *Industrialisation:* To analyse how building services technologies can be modularised, configured and prefabricated, so that greater value is created for clients and users by reducing construction and renewal costs/times, and improving building quality.

2 THE DEVELOPMENT OF INTELLIGENT BUILDING SERVICES

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].

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]. Comparable present 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]. This historical development can be divided into three phases in a Danish context[6]:

2.1 The Industrial Age

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 were 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 public 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].

2.2 The Modern Age

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[9], where very deep building typologies became possible, and where very light curtain wall façade systems with large glazing areas became the norm. 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[10].

2.3 The Intelligent Age

From the 1980's and onwards, developments within the field of information technology have led to a continuing growth in the provision of so-called intelligent building services[11]. 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[12].
- *Entertainment*: The growth in IT, media and communication technologies in today's households, including the development of so-called smart-house systems[13].
- *Control*: The growth of intelligent control systems in all building types, especially related to facilities management and the environmental control of energy consumption, indoor climate, etc.[14].

An important aspect relating to the development of building services is their role in providing the new intelligent functionality which building users' demand[15]. 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[16].

3 BUILDING USE AND BUILDING SERVICES INTEGRATION

With building services being responsible for a large proportion of buildings' functionality, it is now possible to see a transformation in how buldings 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.

Modern society can be characterised by continuing and fluid processes of social and economic change[18], and these processes naturally affect the perception and use of buildings. For offices, dynamic business processes mean that both employees' and the building's ability to adapt over time are seen as innovative competitive prerequisites in their own right[19]. For housing, both lifestyle and demographic changes are affecting the way that housing is perceived[20], 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.

It is clear that these processes of social, technological and economic change and 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[21].

3.1 Building Services Integration in Office Buildings

This integration can be highlighted by looking at the historical development of office design from the 1950's to today. 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 facilites 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.

This transformation of building services requirements has however 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 that have 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[22].

3.2 Decentral Integration of Building Services

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[23],[24]. 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 work environments 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 for their usage.
- 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. This process is shown in figure 1.

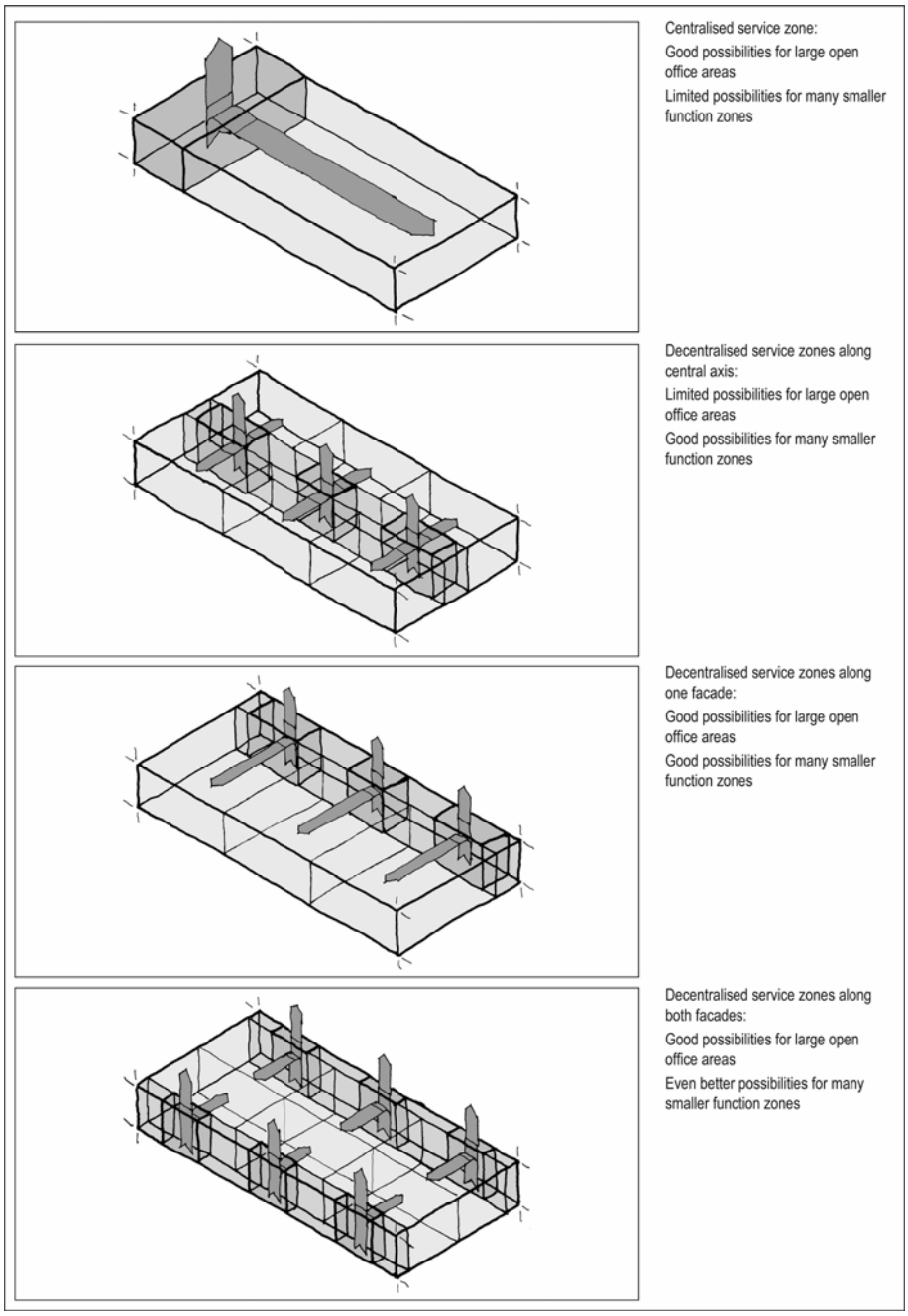

Figure 1: Differing strategies for the positioning of building services distribution[25].

4 INDUSTRIALISATION OF BUILDING SERVICES

The interaction between client, consultant and contractor has historical roots, and 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 higher efficiency has meant that the main efforts to industrialise the building industry have focused on the loadbearing structure and facade elements[27]. 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-intensive) products, are built into buildings in a craftsmanlike way because of the construction sector's traditional organisation.

Studies from the UK have shown that considerable productivity increases in terms of reduced construction costs and times can be found by prefabricating building services[28],[29],[30]. It can 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.

4.1 Building Services Industrialisation in Denmark

There has been very little theoretical or practical work with 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, it has been shown that the prefabrication of building services in Denmark can reduce total construction costs and times whilst also improving the technical quality of buildings[31].

To explore the possibilities of industrialising building services provision in Denmark, a study has been carried out based on data for a typical office building. Construction cost data shows that this building has a construction price of 2.21 Euro/m^2 at 2005 prices[32], and that the building services account for about 30 % of this amount, as shown in figure 2.

The construction costs for the individual building service type can be further broken down with data on 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[33]. By taking each individual building service type that is supplied to the office space in the typical office building, and breaking the construction costs down in relation to the distribution hierarchy, it is possible to see where the largets proportion of the construction costs is placed, as shown in figure 3.

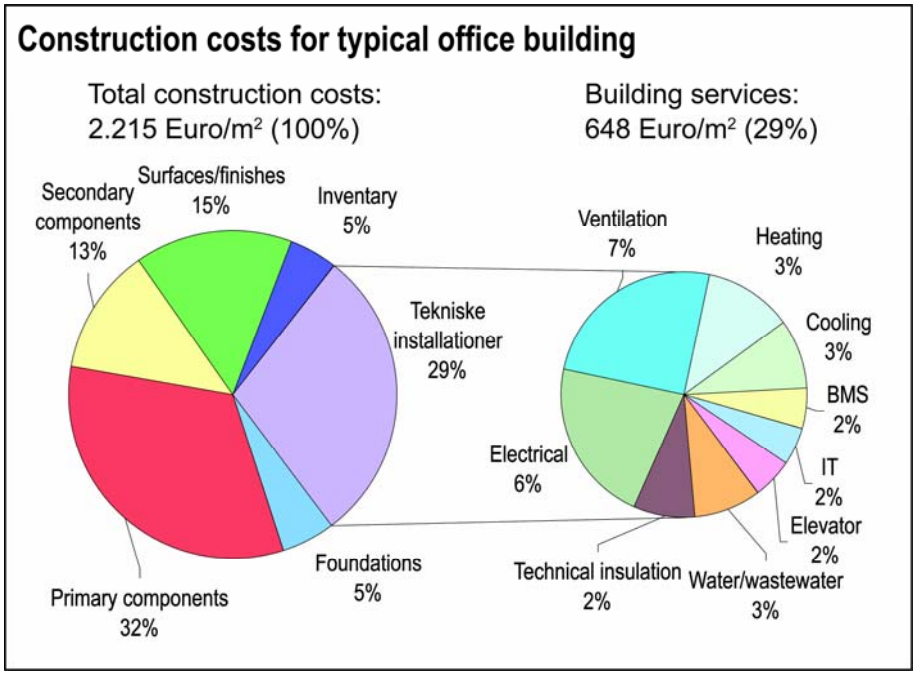

Figure 2: Construction costs for typical office.

Construction costs for building services and distribution to office spaces

	Building services type							
	Heating	Cooling	Tec. isol.	Vent	El	BMS	IT	Total
Construction cost Euro/m²	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 hierachy	Heating	Cooling	Tec. isol.	Vent	El	BMS	IT	Total
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/m²	76	59	52	162	140	34	34	556

Figure 3: Construction costs for building services in relation to distribution hierarchy for typical office.

Here it can be seen that the building services in the loft space, comprising the horizontal distribution (126 Euro/m^2) and local services (134 Euro/m^2), comprise the largest component of the building services construction costs at 250 Euro/m^2. The plant room has the second

highest construction cost at 140 Euro/m^2. 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. 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 suggested decentralised, façade integrated solutions.

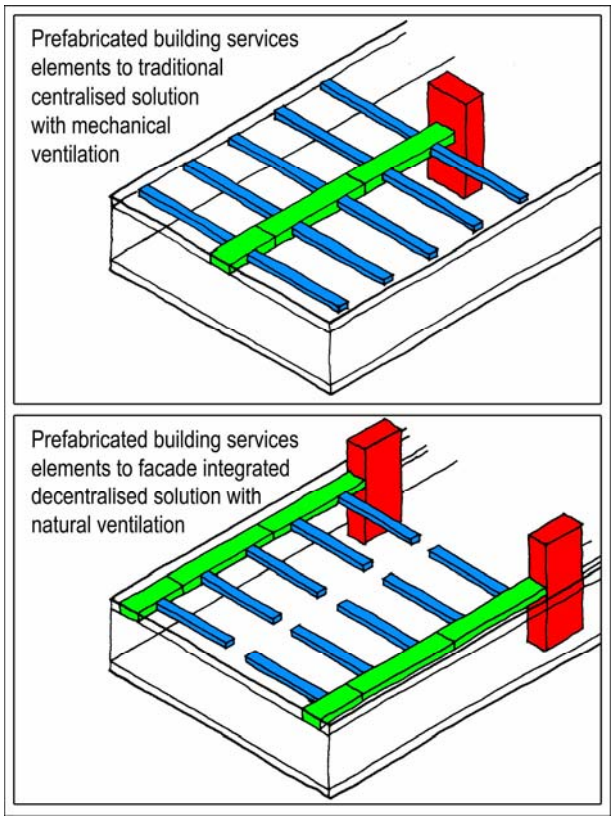

Figure 4: Prefabricated building services elements to loft for typical office

5 CONCLUSIONS

The hypothesis of this paper is that the 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 can be characterised as follows:

- Intelligence: A better understanding of the relationship between changing user demands, functionality and intelligent building services can be created, and that in this way the role of these new intelligent technologies in creating and satisfying changing user needs can be understood.

- Integration: It is possible to propose new strategic design principles which can be used to integrate the expanding range of building services technologies into buildings, so that changing user demands for new intelligent technologies can be incorporated into the building design and procurement process.
- Industrialisation: An analysis of Danish office buildings has been used to show where it is best to focus attantion in developing prefabricated and modularised building services elements, so that greater value is created for clients and users by reducing construction and renewal costs/times, and improving building quality.

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