Multi-dwelling concrete buildings in Sweden : a review of present technology, design criteria and decision making

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MULTI-DWELLING CONCRETE BUILDINGS IN SWEDEN

A review of present technology, design criteria and decision making

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Preface

The authors of this report are doctoral students within the Swedish graduate school "Competetive Building", which was launched in 1999, and which will have a duration of about 10 years. All major technical universities in Sweden are involved in the research school, which will eventually comprise about 30 doctoral students. Almost all of them are employed by private companies, but make their research in collaboration with a university institution.

Both authors of this paper make their research under supervision of the Division of Building Materials at Lund Institute of Technology.

The author Mats Öberg is employed by the cement producing company, Cementa AB. His research project, "The Optimal Concrete Building", is a study of how concrete can be used for building frames, that satisfy essential requirements as regards comfort, flexibility, energy consumption, etc.

The author Markus Peterson is employed by the contractor, Skanska AB. The research project, "Competetive Production of Cast-in-Situ Concrete", is an analysis of how the two new types of concrete, High Performance Concrete (HPC), and Self Compacting Concrete (SCC), can be used in order to rationalise production of cast-in-situ building frames, reducing production cost, and making possible a better utilisation of concrete in buildings.

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Abstract
This report is a brief state of the art review of building technology, design criteria and decision making within the building process concerning multi-dwelling buildings in Sweden. Special attention is paid to the aspects regarding concrete as building material.
Building techniques and technical service systems used in the current production of multi-dwelling buildings in Sweden, are described, and market shares are presented. Concrete and to some extent steel are the predominant materials for the structural frame. The facades are usually rendered or made of brickwork. Hot water radiators supply the heating and the ventilation is normally operated by a mechanical exhaust system equipped with a heat exchanger for energy recovery.
The building process with regard to multi-dwelling buildings is described by analysing the roles of the different participators such as client, architect, contractor and so on. The focus is set on co-operation, competence and decision making. The implication of different kinds of contractual forms is also discussed.
During the last decade the production of new multi-dwelling buildings has decreased. Investors like the public non-profit companies offering apartments for rent have almost abandoned new production for the time being. Instead 'own-development' projects in attractive regions run by the large construction companies, for co-operative tenure, dominate.
The design criteria can be grouped into regulative, which typically deals with safety or health, and non-regulative such as economy, layout or aesthetic design. Attention to environmental issues has increased which encourages long-term/whole life appraisal.
The various aspects and requirements regarding construction as well as functionality interact in a complex way and over a long period of time. The choice of materials and systems during the early project phases are delicate and decisive for the overall building performance. This is emphasised by the de-regulation of the building sector, allowing greater diversity in design.

1. Introduction
The operation and production of the built environment, of which the residential buildings constitute a major part, has a fundamental impact on the society's total economical and environmental balance. Furthermore the home is a key factor the well being of people as well as their private economy.
The building sector in general and the multi-dwelling building sector in particular have been subject to criticism for lack of ('Byggkostnadsdelegationen' [BK])
- customer orientation
- technical innovation
- holistic consideration (integration) with regard to design, production and use
- co-operation between the actors.

The structural frame plays an important part in the process of building production, overall functional quality of a building as well as the life cycle economy. Consequently the structural frame is interesting to focus on for rationalisation of the production chain as well as enhancement of quality from the life cycle perspective.

2. Objective

The objective of this study is to present the state of the art concerning the technology, design criteria and decision making within the building process from the perspective of the structural frame of multi-dwelling concrete buildings.
The study will constitute a base line for two research projects within the Swedish national research programme 'Competitive Building' [CB], one aiming at improved design and production of concrete residential buildings by using new materials and production techniques. The other project pursues enhanced whole-life performance of concrete residential buildings by applying life cycle design. Life cycle design is a method to appreciate and optimise the whole-life functional as well as economical aspects, in the planning and design phases.

3. Methodology

The methods used were studies of literature and statistics to obtain quantitative data. Personal communication with a limited selection of persons representing the different fields of expertise involved within the house-building sector in Sweden, were made to acquire qualitative information, compare list of references.

4. Technology and production methods used today

4.1 Structural frame

4.1.1 General

There are several structural frame concepts available for residential buildings. For single family units and other low-rise buildings prefabricated wooden frames are most frequent and for multi-dwelling buildings the systems described below are used. The market shares, are expressed in percentage of m2 produced in 1998 are distributed according to figure 1, according to a recent survey by Mängda AB and periodical market statistics from Betongelement-föreningen [M1].
Note that there are several possibilities to combine types of building frame, which makes the mapping of market shares somewhat uncertain.

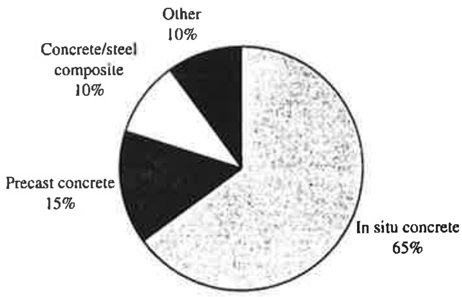


Figure 1. Approximate market shares regarding type of building frame within production of multi-dwelling buildings in Sweden 1998. [M1]

4.1.2 In-situ cast concrete

4.1.2.1 General

In-situ cast concrete frames for residential buildings are normally produced either with tunnel-forms or in combination with prefabricated floor slabs and/or wall units. The thickness of the concrete slab is typically 200 to 250 mm, allowing spans up to approximately 5 m, and 160 to 200 mm in walls. The most common structural layout, the slab block with curtain walls, is presented in figure 2 A 'traditional', below. Other layouts adopted from office buildings such as column-slab layouts, according to figure 2 A 'alternative' are also used.

The 'curtain wall' facades are prefabricated or built on site with studs of sheet steel or wood and cladding of bricks or rendering on mineral wool.
A comprehensive overview with regard to cast in-situ frames, 'Betongbanken', have been compiled by the Swedish Ready-mixed Concrete Association [SFF]. The cast in-situ concrete frame has been the dominating structural concept for multi-dwellings buildings in Sweden in modern time.

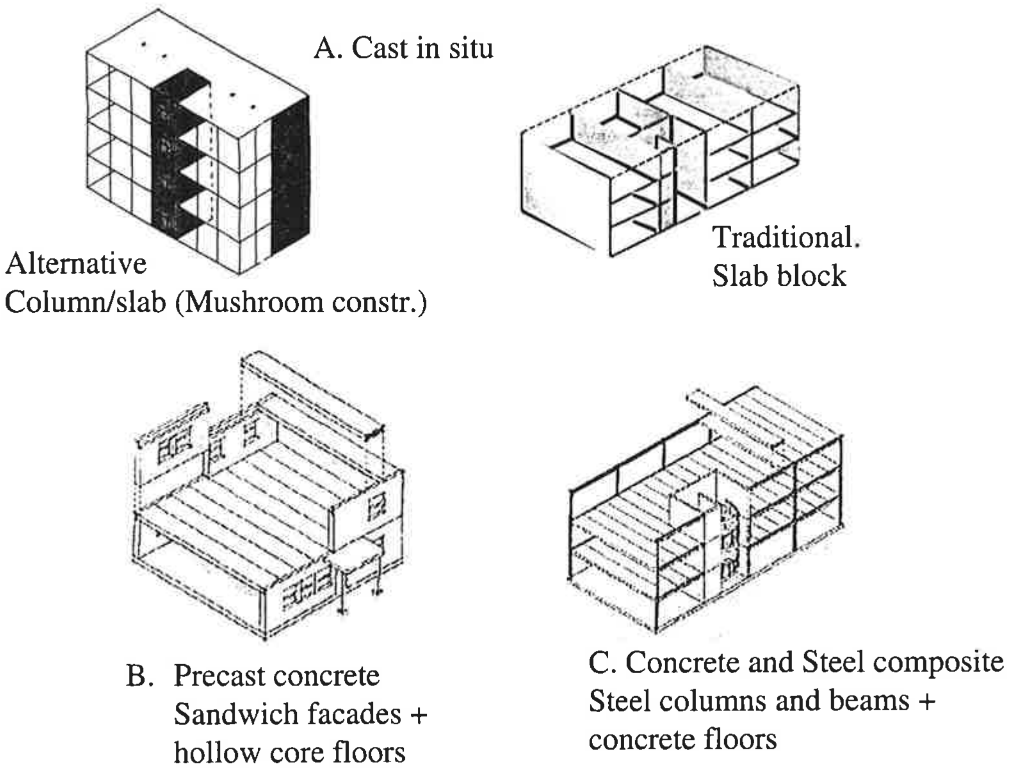


Figure 2. Layouts of common structural frame systems. A according to [SFF] and B,C Skanska Prefab AB. [skal]

4.1.2.2 Concrete technology of today within production of multi-dwelling buildings

In production of structural frames within the house construction sector the most frequently used cast In-situ concrete is an ordinary K 30 with a water-cement ratio, 'w/c-ratio', of approximately 0,60. The reinforcement is generally non-tensioned. The relatively low structural capacity of this concrete and reinforcement allows floor-spans only up to approximately 5 meters. In-situ cast partition walls normally supports the slabs and form solid cell system. Compare figure 2 A, 'Traditional'. This limits possibilities for reconstruction and thus the flexibility for the user.
In office buildings other structural concepts, that allow greater flexibility, are dominant such as the column/slab structure. Compare figure 2 A, 'Alternative', and post-tensioned reinforcement is also used to a larger extent. These concepts are now being introduced for residential buildings.
The traditional low-grade house-building concrete with high water-cement ratio needs long drying times before floor covering can be started, to avoid moisture related problems within glue or the carpet. In the building standards maximum allowed values of the relative humidity, measured on the equivalent depth of concrete construction, are presented. These values depend on the type of material, which is used to cover the concrete floor. For most materials the maximum values are between 85 and 90 % relative humidity, which implies a necessary drying time for an average concrete K30 of several months. During the last years self-drying or quick

drying concrete have been introduced in order to allow earlier application of floor coverings. See further section on High strength concrete in 3.1.2.3, below.
For acoustical reasons (sound insulation) a thick concrete slab is advantageous. However, in practise the thickness of the concrete slab is limited by the extension of the concrete drying times. Partly because of this the highest sound insulation class according to the Swedish building regulations [bbr] is seldom reached.
By the execution of cast in-situ concrete structures of today, the concrete has to be vibrated and compacted with vibrators in a traditionally way. The vibrators cause a lot of noise and work related health problems for the workers, such as "white fingers". Furthermore this method is rather personnel intensive.

4.1.2.3 New material technology

High strength concrete, 'HSC'

High strength concrete is a concrete with a K-value of 80 MPa or more. The high strength is reached by increasing the amount of cement and/or reducing the water content by means of powerful water reducing admixtures. In the HSC the water-cement ratio is reduced to values below 0,40. The high K-value combined with the low w/c-ratio opens advantages concerning structural design, production technique and function.

With regard to the structural design the high strength of HSC enables significantly larger spans and/or slender constructions than an average K 30 concrete. The drying process for a HSC differs from normal concrete. In a HSC the water is bound to a larger extent in chemical and physical form, which implies a self-drying effect, which not only reduces the drying time. Furthermore the drying time becomes nearly independent of the concrete thickness, which for a normal concrete, K30, is a critical factor.
To summarise the structural aspects with HSC it is possible to construct larger spans as well as more slim or thick (for acoustic reasons) constructions.
From a production oriented point of view, the reduced drying time with HSC, allows floor covering to be started in an earlier stage. Of course this also means possibilities for shorter total production time and lower production cost.
An effect of HSC is not only the high final strength but also the fast strength development, which may reduce the production time through earlier form removal or earlier tensioning of post-tensioned reinforcement. The form-work can be used more rationally through shorter form removal cycles. The fast development of strength may also reduce the problems often connected to winter casting, because of the reduced freeze risk of the young concrete. Costs for warming and covering may be reduced, by utilising the fast development of the strength.

The mentioned advantages concerning structural design and production technique may lead to advantages also in the function of the building. Larger spans in combination with light, easy dismountable, partition walls allows a higher grade of flexibility through increased rebuilding possibilities. Concerning the fast drying process an advantage may also be the possibility, in a rational way, to avoid moisture related health problems, which sometimes have been a result of inadequate drying time before floor covering. The self-drying effect can also be used to improve acoustic qualities by allowing thicker slabs, without any extended production time.

Self-compacting concrete, 'SCC'

SCC enables casting In-situ without vibration. The concrete is based on a new type of very efficient water-reducing admixture combined with high filler contents, e.g. limestone fillers or special fine-grained sand.
With SCC there are new possibilities concerning design. For instance, densely reinforced structures, which are difficult or impossible according to traditional methods, can now be produced.
SCC is a solution to the work environment related problems regarding cast in-situ concrete. The white fingers for the concrete workers will be eliminated and the building site will be

significantly more silent without the noise from the concrete vibrators. Furthermore the elimination of the vibration means rationalised casting technique with need for fewer personnel and reduced production costs.
Smooth, high quality surfaces can be produced directly without the expensive finishing work often-needed when casting concrete traditionally.

4.1.3 Precast concrete structure with load bearing sandwich facade elements

A main feature of the precast frame is the use of the prestressing technique in floor elements, which can be either hollow core slabs or massive elements. This allows spans over the entire width of the building. Compare figure 2 B. The hollow core slabs for residential buildings typically have the profiles 1200x200 or 1200x265 mm enabling spans up to 13 m. The concrete used is earth moist (K55-K60) and the elements are produced with extrusion technique, typically on 100 m long beds. When sufficient concrete strength for the release of the prestress has been achieved the slabs are sawn into appropriate lengths. The elements are stacked and finally delivered to site in the appropriate assembly order. Thus the elements can be lifted directly from the delivery vehicle into the appropriate location in the building. The joints between hollow core slabs are filled with concrete on site. Usually a topping of self-levelling grout, (10-30 mm) is applied on the slabs. Alternatively a raised floor, for instance parquet on joists is used. The latter solution allows for installations to be placed in the floors.
The exterior walls usually consists of sandwich wall panels with an exterior, painted, concrete layer (70 mm), usually with a texture similar to rendering, an insulation layer (100-150 mm) and an internal load bearing concrete layer (100-150 mm). Concrete K40 or K45 is used. This is primarily not motivated by need for strength but to allow adequate form stripping time. This concrete also provides sufficient durability against freeze thaw and carbonation without any further measures. Thus no extra air is introduced in the exposed concrete layer.
Systems with short span, plain reinforced massive floor elements and load carrying internal walls in a layout according to the In-situ cast concrete in figure 2 A 'traditional', are also used. Such elements are produced either individually on horizontal tables or as packages, vertically in 'battery forms'. As regarding sandwich panels concrete K40 or K45 is used normally.
Development trends within the precast sector that can be mentioned are for instance new 'architectural' facades such as 'joint free' surfaces and the 'package concepts' such as complete floors or even complete building frames including installations which has been practised by some companies. Looking at the production procedure the introduction of Self Compacting Concrete, mentioned in section 3.1.2.3, adds benefits regarding concrete surfaces, possibilities to produce complicated structures and work environment in the precast plant.

4.1.4 Concrete and steel composite structures

By the end of the 80-ties the steel and concrete composite structures were introduced, copying the concept from the office building sector. The structure normally consists of steel columns of hot rolled rectangular hollow or H-section and steel beams of hot rolled H or special welded profiles. Pre-stressed concrete hollow core slabs, as described above, massive concrete floor slabs with In-situ concrete overlay ('plattbärlag') or lightweight concrete floor elements are used as slabs. For stabilisation, prefabricated, concrete stair enclosures are often used. The facade is a curtain wall similar to that of the in-situ concrete frame, described above, and the interior walls are lightweight structures of plasterboards on sheet steel studs except for the stabilising concrete stair enclosures. Compare figure 2 C.

4.1.5 Steel frame with lightweight decks

This type of structure resembles the concrete and steel composite with the exception that the floors are constructed of layers of sheet steel panels and different insulation materials to obtain sufficient separating characteristics between flats with regard to for instance air, acoustics and fire safety. The system is favourable when the structural weight must be limited, for instance, when floors are added to existing buildings but in regular new production the use has been limited so far.

4.1.6 Wooden frame

Buildings with wooden frame, prefabricated or In-situ built with load carrying timber facades with wood panels, brickwork or rendering on mineral wool as surface material. This is a common frame type regarding single or multi unit low-rise dwellings. By the end of the 90-ties also some 4 to 6 storeys high residential wood frame buildings were erected. This was made possible after changes in the building regulations that earlier prohibited such buildings due to fire safety reasons and by research and development regarding timber structures and their characteristics with regard to for instance stability, acoustics and fire-safety.
Typically the floor is constructed by in layers of different materials with a total height of about 500 mm and integrated special timber lattice girders allowing up to 6 m spans.

4.1.7 Lightweight concrete

Lightweight concrete is used either as expanded clay aggregate concrete or as autoclaved aerated concrete panel walls or block walls in combination with cast In-situ concrete slabs, precast concrete slabs or in some cases with expanded clay aggregate floor elements.
Lightweight concrete components for exterior walls may be homogenous or of sandwich-type with a layer of insulation between internal and external layers of lightweight concrete.

4.2 Technical services

For new multi-dwelling buildings there are several systems for heating and ventilation available. The heating energy is normally supplied from district heating (72% of the heated floor area, in 1996, according to SCB) which is relayed within the building by hot water radiators.
Systems with floor heating or hot air heating have also become technically feasible since super-insulated windows have eliminated the need for radiators located below windows.
The ventilation systems used in residential buildings are listed in table 1, and in figure 3 the market share during different periods is displayed.

Ventilation system	Swedish denomination	Relative production cost*
Natural	S	1,5
Mechanical exhaust ventilation	F	1
Mechanical supply and exhaust	FT	4,3
Mechanical supply and exhaust ventilation with heat exchange	FTX	4,9

*Table 1. Overview of ventilation systems. * Cost for material and installation for ducts and apparatus including necessary building measures. According to [HMW]*

The Natural ventilation system ('S') uses the thermal driving force whereby the used air leaves the building through the ceiling in exhaust ducts and the fresh air is taken in through valves in the exterior walls or through air leaks. Natural ventilation is very quiet, there is no space needed for apparatus and the operating and maintenance costs are negligible. The exhaust ducts must however be 3-times the size of mechanical systems. The main negative aspect is the difficulty to control the ventilation rate. During cold conditions the ventilation rate may become too high which implies waste of heating energy while in hot weather the thermal driving force is not strong enough for sufficient air exchange. Differences in air tightness in various parts of the building may also lead to inadequate ventilation. There are a number ways to modify the natural ventilation in order to improve the performance, such as temperature controlled inlets ('bimetal'), a wind-device on top of the exhaust duct or inlet via snorkels. There is no rational way to obtain heat-recovery with natural ventilation, which of course is a drawback as the ventilation represents one major part [ka] in the energy balance of a building. The choice of natural ventilation in the current production of multi-dwelling buildings is restricted to experimental housing, compare figure 3.

By mechanical exhaust ventilation ('F') the thermal driving force is replaced by fans in exhaust ducts, normally with inlets in the bathroom and the kitchen, where the need for ventilation is

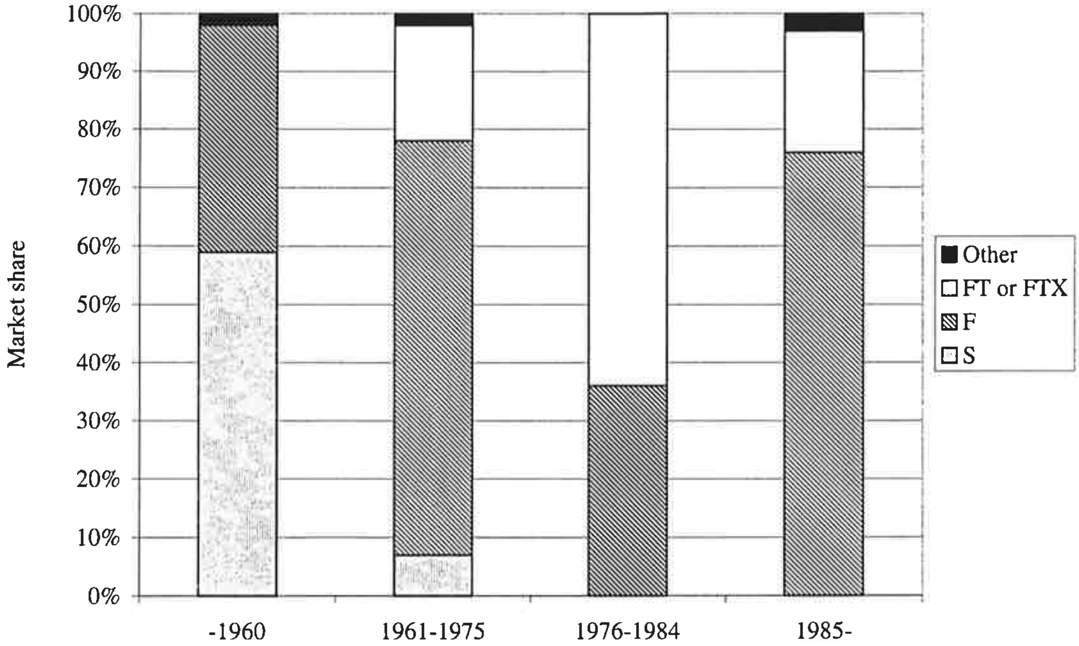


Figure 3. Distribution of ventilation systems in multi-dwelling buildings in Stockholm distributed by age of building, according to [USK1]. FT or FTX = Mechanical exhaust and supply air, F = Mechanical exhaust air, S = Natural ventilation

high and where the noise from the inlet is the least disturbing. By adjusting the inlet valves the ventilation rate can be individually controlled. By shutting a valve, however, the airflow through the remaining open valves may increase to uncomfortable levels as the balance between exhaust and intake air is constant. Special pressure controlled exhaust fans may prevent this effect. In order to maintain a reasonable energy balance in a building with mechanical exhaust ventilation, it is normally equipped with a heat pump that recovers energy for hot water supply. One major advantage with the system is that the building is exposed to a constant under-pressure, which ensures safe moisture conditions within the climate shell, as no damp inside air will penetrate it by convection. The need for maintenance and thus the operating cost of the system is also comparably low.
As indicated in figure 4, the thermal comfort in buildings with F-systems is regarded inferior to buildings equipped with FT-systems. Cold draughts from inlet valves and air-leaks in the climate shell can explain this. Good air-tightness of the building and location of the inlets behind radiators in order to avoid inconvenience of cold draughts are prerequisites to obtain good thermal comfort with F-systems. With regard to air quality the perceived difference between F- and FT-systems is insignificant, according to [USK1]. Compare figure 4.

Mechanical supply and exhaust ventilation ('FT' or 'FTX') adds the possibility to condition the supply air by heating, cooling or powerful filtering of particles. The FT system needs considerably more space for the apparatus and the control system is more complicated compared to the other systems. Increased complexity implies higher maintenance efforts. Special attention must be paid to the supply air part of the system in order to prevent risks for pollution of the incoming air due to, for instance, dirty filters.

The system provides good opportunities for heat recovery. The 'FTX'-system usually uses simple plate heat exchangers between the exhaust and supply air. The FT-system may use a heat pump to recover energy from the exhaust air for hot water production.

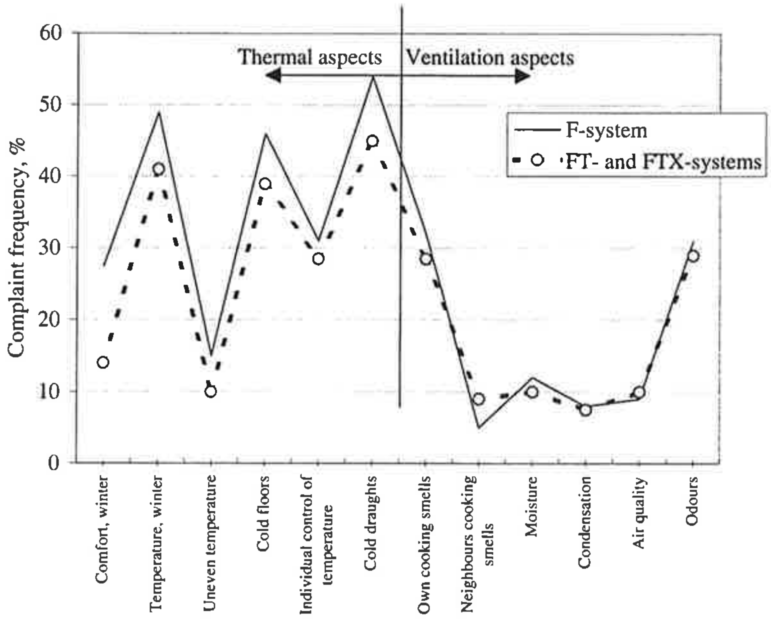


Figure 4. Perceived indoor climate quality distributed by type of ventilation system in multi-dwelling residential buildings constructed after 1985 according to [USK1]

The systems constitute a large part of the overall production (compare section 4.3.2.1, below) and maintenance effort in residential buildings. The physical fitting of systems into the building needs careful consideration to enable maintenance and not to limit the flexibility in use of the building. The function of the systems and its interaction with the building and the users is of utmost importance for user satisfaction and building performance with regard to aspects like indoor climate, life cycle economy and energy use. This is further discussed in section 4.

5. Design criteria

5.1 Design criteria - general

The various aspects and requirements regarding construction as well as functionality interacts in a complex way and over a long period of time. In this article a choice of important design criteria are presented and categorized as regulative or non-regulative. Environmental aspects covers a wide range of, both regulative and non-regulative, criteria and are thus presented separately.

For residential buildings the customer could be categorized as: user, owner or society. Many aspects on the building are of equivalent interest independently of category, such as health or safety, while other, for instance, economy or aesthetics, may differ in importance depending on the category of stakeholder.

In principle the regulative criteria relate to all customer categories while the non-regulative are more relevant for the user and the owner than to society.

5.2 Regulative criteria and public support to the housing sector

The current Swedish building legislation, PBL [PBL] with its application guidance in BBR 99 and BKR 99 [bbr] contains requirements and recommendations regarding accessibility,

structural stability and safety, durability, fire protection, indoor climate (health and comfort), water supply and sewage system, sound insulation, safety in use and energy retention.
The requirements have shifted from descriptive to functional. Their scope has decreased significantly and they have been adapted to the 'Essential requirements' of the EU Construction Product Directive (89/106/EEG). This development has largely increased the freedom as well as the responsibility of the producer. Furthermore the former public involvement with regard to checking of specifications and execution on site has been almost entirely removed. The only area which has acquired increased public concern is the environment, see further section 4.4.
The former comprehensive and detailed requirements were linked to substantial public financial support to the housing sector. The requirements thus not only served to safeguard safety and good housing standards but also the public investment. Consequently the public financial support is gradually pulled back in line with the decrease of detailed normative requirements. Compare the relation between the tax on buildings and the subsidies in figure 11.
In the new deregulated market more differentiation with regard to customer demand will be appreciated. This is demonstrated by recent housing exhibitions such as H99, Helsingborg, were low budget as well as luxury dwellings were displayed. The regulative criteria will serve as threshold values safeguarding minimum standards or general public interest, such as environmental aspects.

5.3 Non regulative design criteria

Referring to the discussion in section 4.1 the non-regulative criteria primarily relate to the owner and the occupant of the building/flat. Depending on the kind of tenure, these can be regarded as the same or different. Looking at functional aspects of a building a simplification may be justified, such as: what is beneficial for the owner is also, in principle, beneficial for the occupant. For example low operating costs corresponds to a low rent.
From the functional point of view many aspects are addressed by the regulative criteria mentioned above there are, however, some important exceptions that will be commented upon.

5.3.1 Functional and aesthetic design and planning

The most frequent layouts of modern Swedish multi-dwelling buildings are slab blocks (lamellhus), point blocks (punkthus) and balcony access blocks (loftgångshus).
In figure 5 their relative distribution in the current production is displayed.

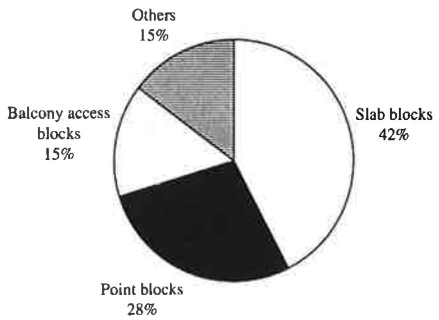


Figure 5. Relative distribution of different types of buildings in the production of multi-family dwellings in 1998. [SCB 1]

As shown in figure 6, the number of storeys in multi-family dwelling buildings in Sweden is predominately either 1 or 2 or between 5 and 8. This can partially be attributed to regulative criteria regarding accessibility (requirements for lifts) and fire protection (fire protection classes) making some solutions more economical. The total height of the building is normally restricted by the city-planners.

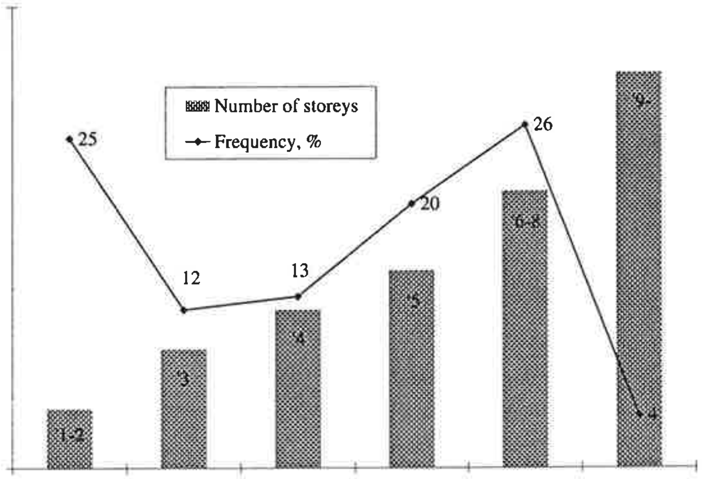


Figure 6. Frequency of different numbers of storeys in the production of multi-family dwellings in Sweden 1998. [SCB 1]

Flexibility is a cornerstone for rational production as well as for use. Flexibility in production implies modular systems where standardised components or technical solutions can be aggregated to a building that is highly customised.
Flexibility in use is characterised by possibility to change certain parts of the building along with changes in the needs of the user, and by disentangled systems allowing for instance maintenance or exchange of technical systems with no or only minor disruption of the structural frame.
Flexibility is thus an important life cycle design feature.
The average number of rooms, including kitchen, per flat in the new production was nearly constant: 3,5 between 1965 and 1990. During the first half of the 90-ties it was reduced to 2,5, which has remained the same until 1999 when a slight increase occurred. [SCB3]
The exterior design of a building is to a relatively large extent dependent on the municipal authorities. The production of new multi-dwelling buildings in Sweden during the end of the 90-ties has been characterised by rather small-scale projects, often in close connection to existing built environment. This has emphasised a tendency to adopt the new buildings to the present style. For example in Stockholm rendered facades strongly dominate also in new buildings.

5.3.2 Economy

5.3.2.1 General

Defining the design criteria for the particular project and transferring them into specifications that will lead to the most economical solution is, to make a reasonable simplification, what the planning and design process is all about. The work is complicated by several circumstances such as

- the possible conflict between low production costs and low operating costs
- the difficulties to predict long term consequences of design decisions
- the interaction between different aspects. For example the pursuit of low energy use could lead to deteriorated indoor air quality.

There is however not only a problem of multiple requirement optimisation in this context; the link between customer value and price within the residential building market is also diffuse. This can be explained by the tradition of regulating the sector with both subsidies and restricted

maximum rent levels, in combination with the relatively high importance of the location of a flat with regard to customer demand.
The total investment in multi-dwelling buildings in Sweden is displayed in figure 7 [SCB1] Note that the total cost for new production is equivalent with the cost for reconstruction during the period in question (1980 to 1996)

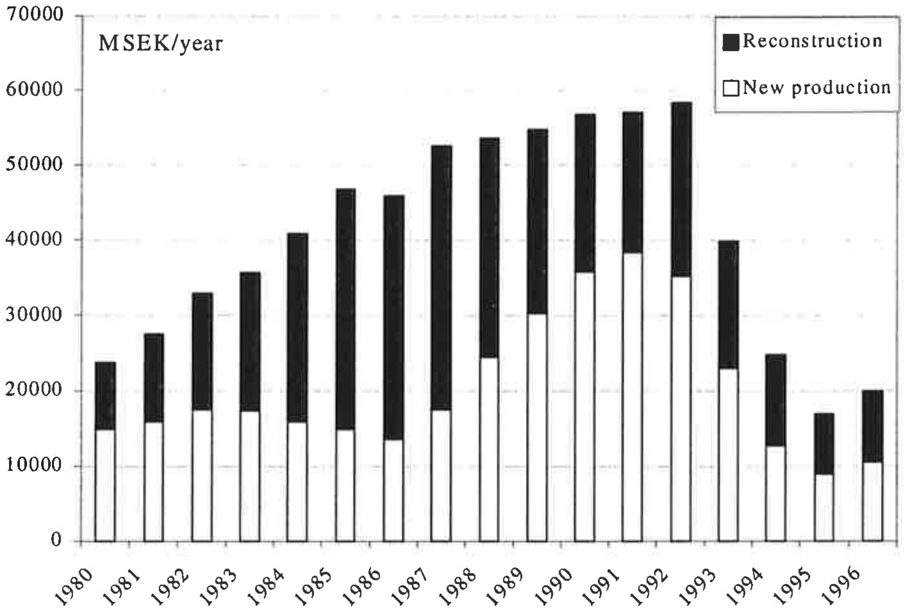


Figure 7. Investment in multi-dwelling buildings in Sweden (Price level 1991) [SCB1]

5.3.2.1 Production costs

The average production cost for multi-family dwellings in 1998 was 13500 kr/m2 according to SCB [SCB2]. Regional differences are displayed in table 2.

Region	Number of units produced in 1998	M2/unit	SEK/unit	SEK/m2
Stockholm	1793	86	1227600	14244
Gothenburg	320	76	1135000	14929
Malmö	226	83	1028500	12388
Other areas				
North Sweden	138	70	824000	11784
Mid Sweden	882	81	913300	11255
South Sweden	573	91	1298300	14260

Table 2. Multi-family dwelling. Productions costs 1998 according to SCB.

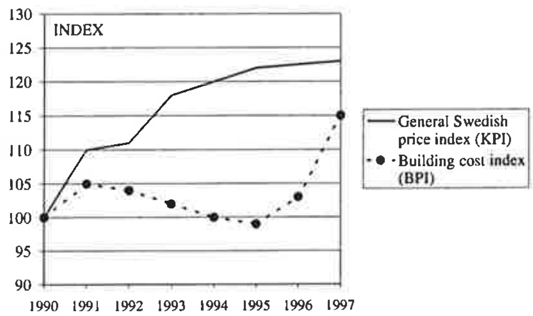


Figure 8. Development of building production costs and general costs according to [AB]

The production cost of dwellings has been intensely discussed and it has been blamed to contribute to the low rate of production of new dwellings in Sweden during the 90-ties, compared to similar countries. Looking at the last decade, compare figure 8, the increase in production costs has been lower than the increase of general Swedish prices. A longer perspective reveals a tight connection between increase in production costs an intensive market situation On national level a specific body was appointed in 1996, to look into the matter and pursue change: the Building cost commission, 'Byggkostnadsdelegationen'. Several full-scale experiments have been initiated looking at improvements of technology as well as building-process. A report from the commission was published in May 2000. [BK] The conclusions are presently being discussed by the building sector in Sweden.

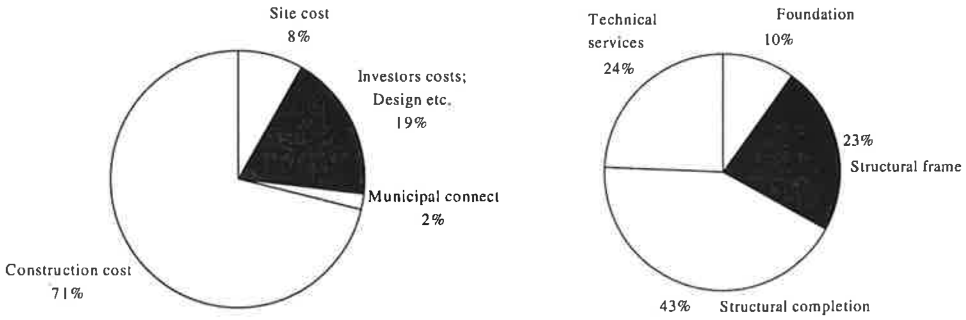


Figure 9. Typical distribution of production costs for multi-family dwelling blocks. A: Entire building cost. Andersson, Borgbrant 1998. [AB]. B: Construction cost. JM/SBUF 1996. [JM]

The distribution of production and construction costs is displayed in figure 9. Note that the relation between cost for the structural frame and structural completion is dependent on the structural concept in question. For instance partition walls or exterior walls may or may serve as part of and thus count as part of the structural frame. In the displayed case the type of frame is a traditional cast in-situ concrete structure.

5.3.2.2 Operation costs

The operation costs reflect the use of energy for heating, hot water, lighting, elevators and other applications, maintenance of the building and finally services like cleaning of common areas and waste handling.

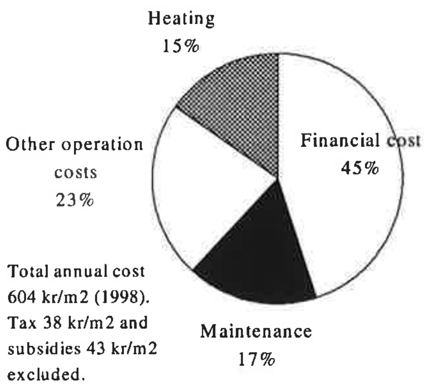


Figure 10. Distribution of overall costs for an average multi-family dwelling 1998, according to SCB. [SCB1]

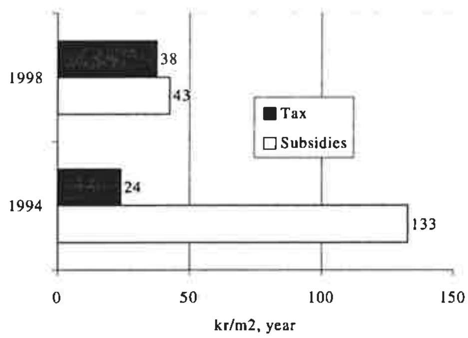


Figure 11. Subsidies and taxation of multi-family dwelling buildings according to SCB.[SCB1]

5.3.2.3 Overall costs

The total cost for the dwelling consists of capital costs related to the production, operating costs, maintenance and administration. In figure 10 the distribution of overall costs for multi-family dwellings are displayed. In average the total cost is 604 kr/m2,year (1998), according to SCB. [SCB1].
The most significant change regarding overall economy is the relationship between subsidies and taxation. Compare figure 11.

5.4 Environment

5.4.1 General

Earlier the environmental issue was confined by the building-industry to work environment and reduction of local environmental disturbances from production plants and sites. During the 90-ties the environmental concern has expanded into the areas sound indoor environment and regional and global ecology. This is summarised in the concept of sustainable construction that was defined in 1994 [sus]*'The creation and responsible maintenance of a healthy built environment, based on ecological principles, and by means of an efficient use of resources'*.
On the Swedish national level 15 environmental quality goals have been defined. [r] One of these applies to buildings: No.11. 'Good built environment'. The National Board for Building, Housing and Planning ('Boverket') has adopted and presented this goal in the report 'God bebyggd miljö' [Bov1] which gives specific and, where possible, quantified guidelines and proposes action plans to the building sector. The topics most relevant for the production of new multi-family dwellings are indoor environment whereby ventilation, moisture control, noise protection and the prevention of legionary disease are discussed and the economising of the use of materials, water and energy.
For example it is stated that the energy use within buildings should be reduced by 50% in 2050 compared to 1995.

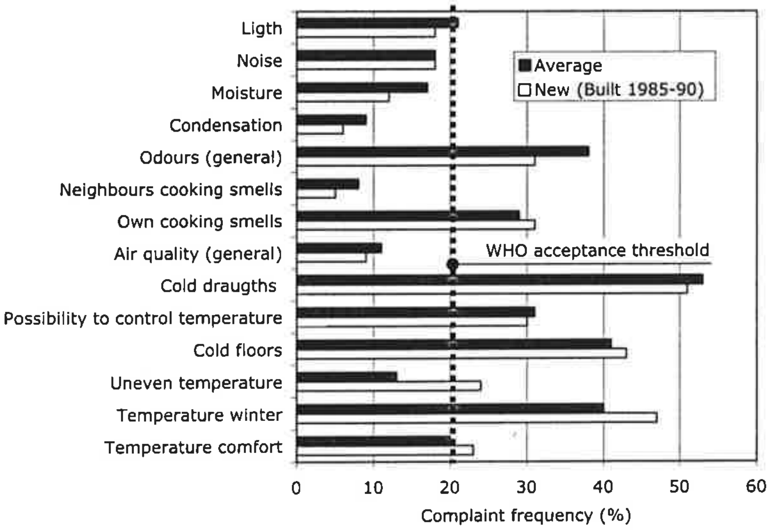


Figure 12. Complaint frequencies for residential buildings in Stockholm. [USK1]. New = Built 1985-1990. Average = All dwellings

5.4.2 Indoor environment

The introduction of stricter energy saving standards, new materials and new combinations of materials, new rapid production methods, new chemicals used within the household and changed occupant behaviour have in some cases triggered comfort or even health complaints.

Referring to a study in 1992 [USK1], regarding occupant satisfaction with indoor climate within 10000 households Stockholm, compare figure 12, it can be noted that

- there has been no significant improvement in new buildings compared to old
- the buildings do not live up to the occupants expectations with regard to indoor environment as about half of the aspects addressed have a complaint frequency beyond the WHO threshold level

A massive research effort within this field has not yet been able to establish reliable cause-effect relationships. [W]
Important factors, also recognised in [Bov1], are efficiency of ventilation systems including design as well as quality assurance of production and use, moisture safe structures and materials and moisture design and quality assurance of production, emissions from materials and finally sound insulation within a building and towards the outside.
According to the Stockholm study [USK1] the aspects regarding indoor air and temperature, that were ranked most important by the users in multi-family buildings, constructed after 1985, are:

1. I can not control the ventilation in my flat
2. I can not control the temperature in my flat
3. The air is to dry in my flat
4. The floors are to cold in my flat

Note that perceived dry air by irritation of eye and upper airways can not always be physically explained by low relative humidity but also to irritants from the O_3 oxidation processes in the indoor air. [W]

5.4.3 Global ecology. Energy and resource use

The built environment has a substantial impact on the regional and global ecology. In Sweden approximately 40% (160 TWh) of the total energy use, 50 % (71 TWh) of the use of electricity, as well as a large proportion of all raw materials used can be referred to the building sector. [Bov1]
As shown by table 3, below, the main contributor (84+5 %) to the energy use regarding the buildings lifecycle is the user-phase.

	kWh/(m2x50 years)	Share (%)
Production of materials and components	820	9
Transports of materials and components	30	-
Building site	120	1
Use (heating, hot-water, light, other electricity)	7500	84
Maintenance and repair	410	5
Demolition	< 10	-
Demolition material transport	20	-

Table 3. Energy use over the lifecycle for a new Swedish multi-family residential concrete building, according to Adalberth, LTH, 2000. [ka]

The goal according to [Bov1] is that the total energy use (heating, hot water and electricity for the household) should be 90 kWh/m2,year by 2010 and 60 kWh/m2,year by 2020 in the new residential buildings. This should be compared to an average of 180 kWh/m2,year in the entire Swedish stock of residential buildings or 150 kWh/m2,year in the current new production.
Longevity-durability and need for maintenance are important aspects when comparing different products or systems from life cycle ecological as well as life cycle economical point of view. Guidance on this topic can be found in building norms, by owners and in research reports. One practical tool for design life prediction is described in a recent report from a project initiated by The Swedish Building Material Group, ('Industrins Byggmaterialgrupp'). [y]
This information can be systemised in a maintenance plan according to the example in table 4, from former 'Byggnadsstyrelsen'.[KBS].

Part/type	Design-life (years)	Maintenance interval (years)	Action
Facades			
Rendered	30	15	Repair
Brick	60	20	Joints – overhaul
Sheet steel	60	15	Painting
Wood panel	60	10	Painting

Table 4. Example of maintenance plan. [KBS]

The development of the total stock of flats in multi-family dwellings is displayed in figure 13 It should be noted that the rather high number of removed flats during the late 90-ties refers to

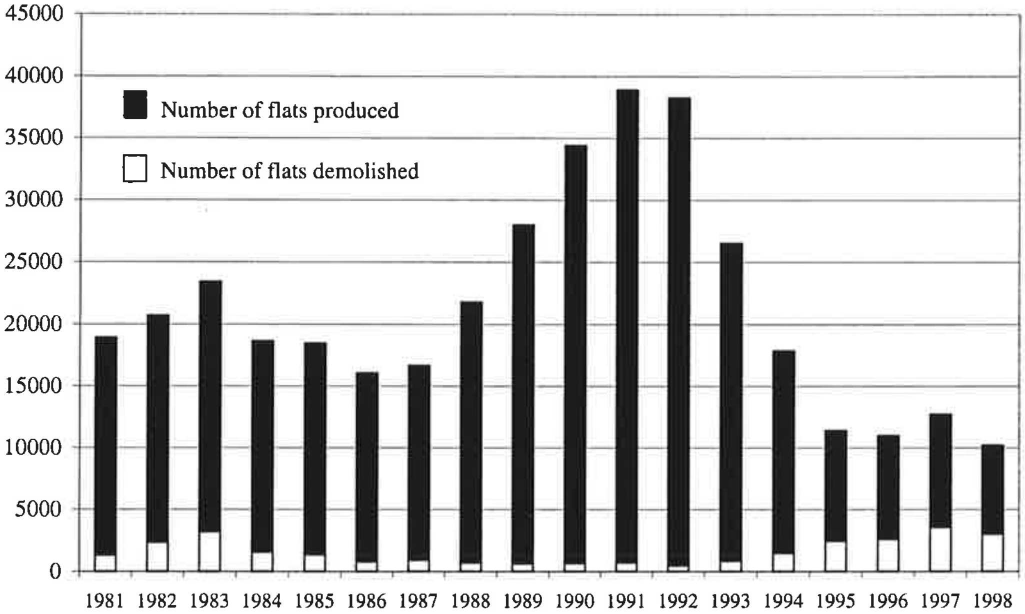


Figure 13. Changes in the building stock of multi-family dwellings in Sweden. [SCB1]

adjustment of building stock in areas other than the metropolitan areas. For example in 1998 3025 flats were demolished of which only 336 (11%) were located in the vicinity of Stockholm, Gothenburg and Malmoe.

5.4.4 The impact on the building industry

On a national level the Swedish building sector established a council for environmental issues in 1996 ('Byggbranschens kretsloppsråd') with representatives from owners, consultants, construction companies and material producers. This council constitutes a link between the building industry and the authorities and is a co-ordination forum for environmental development.

One example from the action plan defined by this council is a commitment to provide environmental declarations for all products and materials that are incorporated into buildings. The declarations address global-ecological as well as indoor environment aspects. Resource use and emissions to air and water by production processes and transport of materials and components, and also self-emissions to indoor air of for example volatile organic compounds and formaldehyde are quantified in the declarations.

In order to obtain data for the declarations many producers today use life cycle assessment or life cycle inventory.

Regarding indoor environment a research program comprising 15 research projects have been launched based on co-operation between universities and companies and supported by national strategic research funds. [kk]

On company level environmental control systems have been introduced and there is a growing awareness of the environment issue as being a marketing tool.
Systems for environmental benchmarking of buildings and building-products are available and some companies, especially construction companies, also develop their own systems for the selection of products.
Producer respond to the market by developing new environmentally lean products or by improving production processes with regard to, for instance, energy and material use or generation of waste, often using life cycle assessment as a decision making tool.
A conclusion is that environment will be a key agent for change within the building sector in the coming years.

5.5 Design criteria – concluding remarks

The design process can be described as multiple-criteria decision making with an innumerable amount of possible solutions. To complicate the situation many of the functional aspects are interrelated and furthermore different technical components and systems such as the building frame, the building envelope, the ventilation and the heating system interacts.
A striking illustration of this complexity is how the perceived indoor climate developed after the so-called energy crises in the 70-ties. In order to limit energy use (economical reason) the heat insulation increased substantially and systems for heat recovery of exhaust ventilation air were introduced. This led to <u>improved thermal comfort</u> but also <u>increased building related health problems</u>. [USK1]

6. The house-building process – contract models and actors

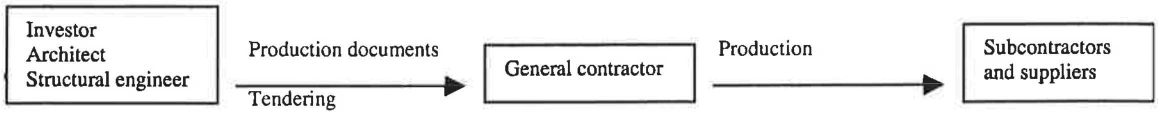
This chapter is largely based on personal communication with persons within the building sector. See the references. The persons interviewed have by their expert knowledge been selected with the aim to cover meaningful areas within the housing sector regarding to planning and production of multi-dwelling buildings. Important to notice is that this chapter consists of a summary of personal opinions concerning house building.

6.1 The Contract models

The possibilities for the different actors to influence, for instance, the choice of structural frame, is largely dependent on contract form used in the particular project. In the general contract model the investor in co-operation with the appointed consultants are the decision makers, and they produce the production documents. Thus the possibilities with regard to the influence on design of the building, for the general contractor inclusive subcontractors and suppliers are nearly none. Compare figure 14.

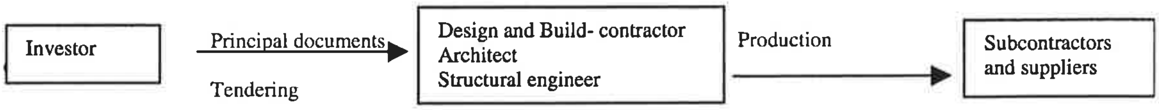
A contract model with some similarities to the general contract is the *divided contract*. The difference is that by the general contract the general contractor is responsible for production co-ordination while by the divided contract the investor or the appointed construction management consultant takes this responsibility.
In the case of a *design and build contract* model, there are greater possibilities for the contractor to influence the decision of structural frame and other aspects of the building. The investor provides only principal documents and the contractor is responsible for the production documents. Compare figure 14.
A design and build contract model also tends to give more opportunity to subcontractors and suppliers, like the ready mix concrete producer, to influence the design.
A special concept closely related to the design and build model is the *own development model*, whereby the investor and the main contractor are within the same company.

General contract



The structural frame is decided

Design and build – contract



The structural frame is decided

Figure 14. Influence on design decisions depending on type of contract.

6.2 The actors - general tradition and trends

The building sector is sometimes criticised for being not as modern as the manufacturing industry from an organisational and process oriented point of view. The major arguments concern the co-operation between the, in many cases, large number of actors which are involved in building projects. Especially the co-operation between the actors in the early stages of the project, the planning process, is criticised for being less developed compared to the manufacturing industry.

Some state that the house-building sector is conservative and traditional which makes innovations difficult to implement. This can to some extent be contributed to the fact that buildings have to be safe and functional for a very long period of time and that malfunction often causes dangerous and expensive consequences.

This chapter aims at describing the roles of the major actors in the house building process namely the client, the architect, the structural engineer, the contractor, the ready mix concrete producer and the concrete element producer.

The focus is set on these actors regarding co-operation, competence and tradition.

Within the housing sector some actors in the production process seldom are involved in the planning process. For example subcontractors or material suppliers, such as the ready mix concrete producer, do in most cases not co-operate with the architect or the structural engineer. What the reasons behind this tradition are, what its effects are and the possibilities for change will be discussed below.

Today the production of multi-dwelling buildings is dominated by the contract 'own development projects', see figure 15. Many persons within the house-building sector believe that this concept promotes a higher grade of co-operation and feedback compared to traditional project forms, especially the general contract. On the other hand the concept is criticised for being too much focused on the production phase and based on company standards and that the influence of some important actors, especially the architect, may be to small. Many believe that these participants have to break their own traditions if they want to be more active during the whole building process.

Some trends influenced by the manufacturing industry can be seen in the house building sector today. It is increasingly common that the contractor uses 'system thinking' as a strategy. For example with regard to single family houses the productivity increased with 45% between 1968 and 1997 by integrating the process of design, production and erection while the corresponding increase for multi-family dwellings was only 15%. [BK]
It is unclear if the 'system thinking' trend will increase in the future and what consequences this will have for building process. A short discussion will be performed in the following.

6.3 The client

The client is in this context defined as the owner of the building.
The type of ownership and form of tenure is distributed according to table 5.

State	1%		Rented
Private	26%		Rented
Public non-profit organisation	41%		Rented
Co-operative	32%		Owned share
Of which are nation-wide organisations		22%	Owned share

Table 5. Ownership distribution for multi-dwelling buildings in Sweden 1998. Percent of number of flats, according to [SCB4]

As can be seen in figure 15, the drop in production during the last years is entirely related to rented dwellings. This can be attributed to several reasons with financial as well as political background that will not, however, be discussed in this paper.

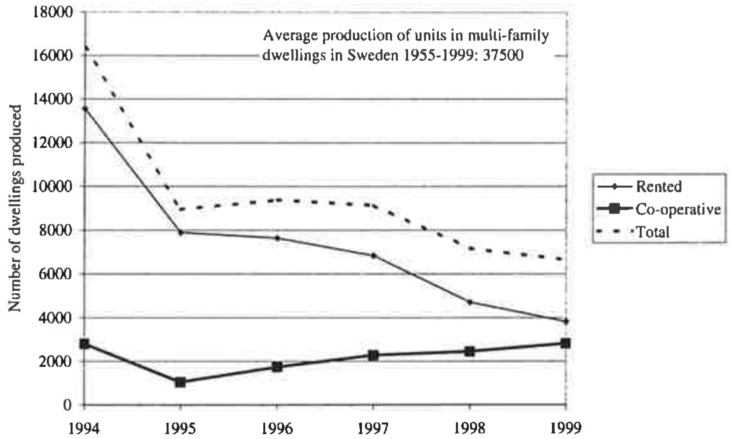


Figure 15. Swedish multi-family dwellings: Number of units produced distributed by form of tenure. Special housing such student or old people homes is not included.

The co-operatively owned houses are managed either by national organisations or private co-operatives, usually only representing one building or one block. The increased number of own-development projects shown in figure 15, above, relates to the private type were the developing construction company relays the ownership of the building to a co-operative formed by the habitants a few years after the construction.
The total number of flats in multi-dwelling buildings in Sweden is 2.103.100 and the total dwelling space is 140.503.000 m2 (1998), according to [SCB4].

When looking at the current level of new production, compare figure 15, note that the average over the period 1955 to 1999, 37500 units, is more than 5 times higher than in 1999

6.4 The architect

Traditionally, the architect has the key role in the planning of the building and thus the responsibility, with the assistance of structural and technical supply engineers, for the overall

functional and esthetical quality and for the adaptation of the new building into the local environment.
Regarding multi-dwelling buildings it is increasingly common that big construction companies such as JM, NCC and Skanska produce residential buildings as own development projects, see figure 16. In order to increase productivity standardised housing concepts are being introduced. It is generally acknowledged that the productivity issue is important and pressure has been put on the building industry to address this. [BK]
Consequently it is necessary that the standardised concepts are sufficiently flexible and open not to obstruct the freedom of the architect and furthermore attention should be paid to the risk that the architects role could be limited in the context of own-development projects with company based, standardised technical solutions.
In Sweden the architect is primarily involved in the early stages of the building process, which differ from the situation in many other countries where the architect is involved during the whole building process. In Denmark for instance 1/3 of the architects work is related to the production phase. Further to the obvious advantage of the architects increased learning from improved feed back from the production this safeguards the realisation of the overall quality of the building.

6.5 The structural engineer

Similarly to the architect, the Swedish structural engineer has a rather limited dialogue with the contractor and the material suppliers such as the ready mix concrete producer, both at the design stage and during the execution phase.
There are probably differences in the quality of the dialogue, depending on whether the structural engineer is hired as a consultant or employed in house by the contractor. The competence in production technique and material technique is often not as high as it could be, maybe due to ambiguity of responsibility.
The co-operation between the structural engineer and the contractor on the one hand and the ready mix concrete producer on the other differs when comparing house building with civil engineering structures. The average structural engineer in civil engineering has significantly deeper knowledge in concrete technology compared to the structural engineer within house building. In civil engineering construction there is also normally a frequent dialogue between the actors concerning advanced concrete technology. Many of the persons interviewed mean that this dialogue very often is missing within the house building sector, where the concrete structural frame is considered less important than for bridges, tunnels etc.

6.6 The contractor

As shown in figure 16 the contractors role as a general contractor has in principle been exchanged to the own development contractor role.
By some of the interviewed persons the own development and the design and build models is said to encourage more production-oriented design and choices of materials. The competence and knowledge of each actor can in easier way be shared to the project thanks to the open dialogue.
It is believed by many of the persons interviewed that in the previously often used general contract model within the house-building sector, the contractor could not influence the planning process, which made the investor together with the hired consultants the decision makers in the early stages of the house-building process.
In the design and build contract form, there are maybe more opportunities for the contractor to influence the planning process. But some state that even in this contract form 'system thinking' including feed back and open dialogues with the subcontractors, like the concrete producer, is seldom established.
The interest in and usage of new techniques in material or structural design has often been low in the housing sector compared to the civil engineering sector. But within the new concepts created in the own development contract model, the possibilities for using new production,

design, and material technique can be clearer, if the actors are able to have an open dialogue during the planning process and feed back during the production phase. Maybe these concepts can increase the usage of new technology without creating questions concerning responsibility, which often is described as a problem today when introducing new technology.

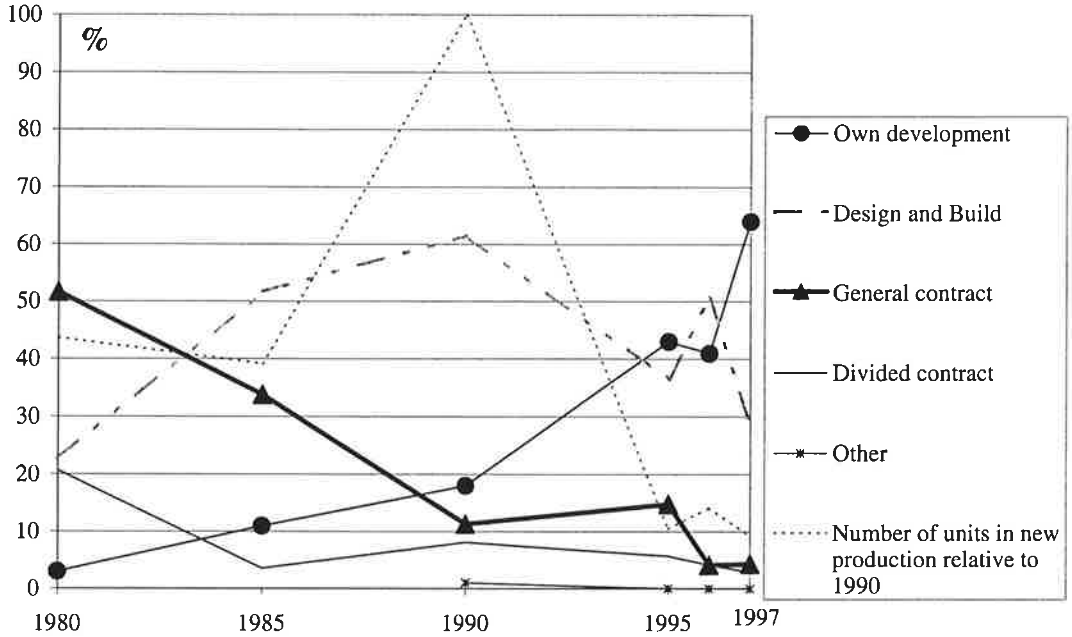


Figure 16. Production of multi-family dwellings in Sweden: Contract models proportion and relative production quantity, according to SCB. [SCB1]

6.7 The ready mix concrete producer and the concrete element producer

With reference to the two research projects, mentioned in paragraph 1, special attention is paid to the roles of the concrete and concrete element producers, which makes this sub chapter larger than the others.

During the so called 'Million Programme' in Sweden 1965-1975, over 1 million dwellings were constructed. Some persons interviewed believe that the huge amount of ready mix concrete and precast concrete elements that was needed, influenced the attitude of the concrete producers; the ready mix concrete producer did not have to make any big efforts in marketing the product. It was selling itself. The precast industry developed systems adapted to fit large-scale projects with great repetitiveness, and large precast plants were in operation in the vicinity of the larger cities.

During the time after termination of the 'Million Programme' until today, the production of ready mix concrete for the housing sector as well as the production of multi-family buildings has decreased.

The way of thinking and traditions which were created during the Million Programme period are however still very strong, especially in the parts of Sweden remote from the big city areas and where there is a lower grade of competition between the concrete producers.

The ready mix concrete producers are seldom engaged in the early stages of the house-building process. Due to this it is almost impossible for the concrete producer to influence the planning. In most cases, and especially in the low competition markets, the concrete producer can be described as just a supplier of concrete to the building site.

The co-operation with the architect and structural engineer is almost none. However during the last years a fairly close co-operation with the contractor concerning the question of how to control the drying out of the construction water, in order to secure a healthy building has been

established. This question often forms the decision criterion for the choice of concrete type because of close link to the production time and production costs.
Another concrete development that has been tried increasingly in house-building, is the self compacting concrete, SCC, which also makes the need of a clear dialogue between the concrete producer and the contractor necessary.
The collaboration of the ready mix concrete producer with other actors of the building process is normally limited to the contractor and in most cases this occurs after the planning process. The potential advantage of interaction in the early stages can be illustrated by the example of the structural engineer making structural use of a high concrete strength dictated by drying out criteria. The other actor's technical knowledge is often considered inadequate by the concrete producer, which limits possibilities to reduce production cost and increasing the technical performance of the building.

Spreading new material knowledge within the housing sector is maybe difficult, because of low interest in concrete technique within the sector and low technical competence in the ready mix industry, especially in the low competition markets.
The marketing arguments for the concrete element producer in comparison with the ready mix concrete producer, partly are that the element producer is able to offer a total concept including structural design, which is almost impossible in the concrete cast in- situ alternative.
One way to establish co-operation between the different actors in the housing production sector is to create companies which act both as material producer, structural engineer and contractor for the structural frame. In Gothenburg the ready mix concrete producer Färdig Betong AB has started co-operation with contractors by forming a structural frame company and in Stockholm the construction company JM AB has introduced a special structural frame organisation 'Stombyggnadsbolaget'. This seems to be one way to get more 'system thinking', feed back and clear definitions of the responsibilities of the different partners involved in the production of the building frame.
As already mentioned the precast concrete producers can offer more or less complete packages of structural frames including the design and erection phases. Some producers such as SCF Strömsund AB, Skanska Prefab and Strängbetong AB have developed complete systems for multi-dwelling buildings incorporating not only the structural frame but also finished facades including windows and technical systems for heating and ventilation. To exploit the precast technology properly it is deemed necessary that the precast producer should be engaged early in the project planning process.

6.8 The Actors – summary and discussion

It is believed by many of the persons interviewed that the tradition of planning and constructing the structural frame in the housing process, is characterised by low interest regarding development of new design, new material and new production techniques. This together with the low grade of co-operation between the actors involved means that the potentials of the concrete cast in-situ structural frame or the precast concrete frame is not fully exploited. During the last years, new material techniques such as self compacting and high performance concrete have been developed. But the usage of these techniques in the house-building sector is considered as not established to the degree that it ought to have been. A more frequent use of these techniques would probably result in advantages in design, production and function of the buildings.
If new techniques will be integrated in the housing process, the tradition of low degree of co-operation between the actors and the low interest in developing the structural frame, must have to be broken. A higher grade of co-operation may create new possibilities concerning the use of newly developed and modern techniques.

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