The optimal concrete building : a research project : background and introduction

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THE OPTIMAL CONCRETE BUILDING

A research project

Background and introduction

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PREFACE

A national Swedish graduate school and research programme for the Swedish building sector called "Competitive Building" was launched in 1999. The programme involves Departments from all major technical universities in Sweden. After an initial period of a few years about 30 doctoral students will be involved in the school, which will have a duration of at least 10 years. Almost all of the doctoral students are employed by private companies within the Swedish building sector, but make their research in co-operation with a university department. The research work is financed by companies taking part in the project, by governmental research funds and by the Foundation for Strategic Research.

The research school is divided in two parts.

- Industrialised building for good living standards
- Rationalised property redevelopment

The author of this report, Mats Öberg, is employed by the cement producing company Cementa AB and is one of the doctoral students in the research school. His research project is performed in co-operation with the Department of Building Materials, Lund Institute of Technology. His doctoral project, which started in January this year, is outlined in the present report.

Lund, May 2000-05-03

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THE OPTIMAL CONCRETE BUILDING
A RESEARCH PROJECT
BACKGROUND AND INTRODUCTION

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ABSTRACT

This paper outlines a research project with the purpose of improved life cycle performance of residential concrete buildings.
The current situation is described and a number of potential improvement areas are highlighted.
The core of the project is a more systematic definition of the functional requirements over the life cycle and enhanced knowledge of their mutual interaction and their interaction with the building structure.
Methods for integrated life cycle design and optimisation will be pursued. Technical, economical, environmental as well as design process aspects will be considered.
The findings will finally be evaluated with a full-scale demonstration project.

1 INTRODUCTION

1.1 GENERAL

Production and running costs could be reduced and the functional performance could be improved, by applying and emphasising a holistic view on

- buildings as systems regarded in life cycle perspective,
- the design process, the choice and production of materials and components,
- the building process,
- the way of operating buildings.

The structural frame of the building is a key factor for the functional properties and is therefore strategic when looking at the life cycle performance.
This study focuses on residential buildings in Sweden but can to some extent also be relevant for other types of houses.

The Optimal Concrete Building is a research project within the national building research programme 'Competitive building' which is partially funded by the Foundation for Strategic Research. This paper describes the background to and the features of the project.

1.2 CURRENT SITUATION

1.2.1 Market and building process

The link between the client/end-user and producer (designer/contractor/..) is weak compared to other technical products such as cars and also compared to other building objects such as industrial buildings or bridges. This applies for the functional requirements as well as the price (rent/investment) for the product.

The technical and economical development within the housing sector in Sweden after World War II has, until recently, been largely dependent on the political scene. There has been a strong social emphasis to provide homes for all people, of a certain minimum standard and to a certain maximum cost for the individual. To attain this the regulations regarding the technical and planning contents of the home have been very detailed and the price has been manipulated by strong general subsidies to the producers, liberal tax deduction rules and strong extra state rent-allowances to households.
In addition to this the whole building industry has been used to smoothen out the ups and downs in the general economic situation in the country.
The state has thus greatly influenced the product it self and the price. During the last decade the state involvement has decreased. Compare figure 2, below.

The fragmented building process is not ideally adapted to achieve the best life cycle value for the client as each actor strives to optimise his profit from each project. Furthermore it is deterring to share knowledge and experience that may be needed to facilitate the best overall result, with project partners that are likely to become competitors in the next project.

The process is focused on minimum production cost rather than life cycle economy.

1.2.2 Structural frames used today

There are several structural frame concepts available for residential housing. For single family units and other low-rise buildings prefabricated timber frames are most frequent and for multi-story dwellings the following systems are used:
* In-situ cast concrete slab blocks with curtain walls. The curtain walls are prefabricated or built on site with studs of sheet steel or wood and cladding of bricks or rendering on mineral wool. Sometimes prefabricated floor slabs and/or wall units are used together with the in-situ concrete.
* Precast concrete structure with load carrying sandwich facade elements. The floor elements are pre-stressed hollow core slabs or massive elements and the facade surface is usually painted and has a texture similar to rendering.
* Steel frame with pre-stressed concrete hollow core floors alternatively floor slabs with in situ concrete overlay. The facade is similar to that of the in-situ concrete frame.
* Timber frame prefabricated or in situ built with load carrying timber facades with wood panels, brickwork or rendering on mineral wool as surface material.
* Load carrying lightweight concrete (expanded clay aggregate or aerated concrete) panel walls or block walls are also used in combination concrete slabs. Due to energy saving reasons these are usually of sandwich-type with a layer of insulation material in the middle.
Looking at market shares for multi-story dwellings concrete systems dominate. Steel/concrete composite frames have been used since the late 80-ties and the entirely lightweight timber (or steel) frames have been introduced in the late 90-ties and are less frequent.

Regarding technical supply systems there is also a set of different technical solutions available that are briefly described in section 2.4.5, below. The cost for these systems has increased significantly in comparison with, for instance, the structural frame. With reference to several studies and statistics apparently without adding any substantially increased customer value, regarding aspects such as indoor air quality or energy economy.

1.2.3 Customer satisfaction

In figure 1 below, the complaint frequencies regarding some important residential quality aspects in multi-family buildings in Stockholm are displayed. This data was collected within the study 'Stockholmsundersökningen' 1991. [1].
According to WHO the threshold for an acceptable situation is 20% complaints. With half of the aspects receiving complaints above the WHO threshold for new residential buildings and no positive trend when comparing new and average the need for improvement is evident.

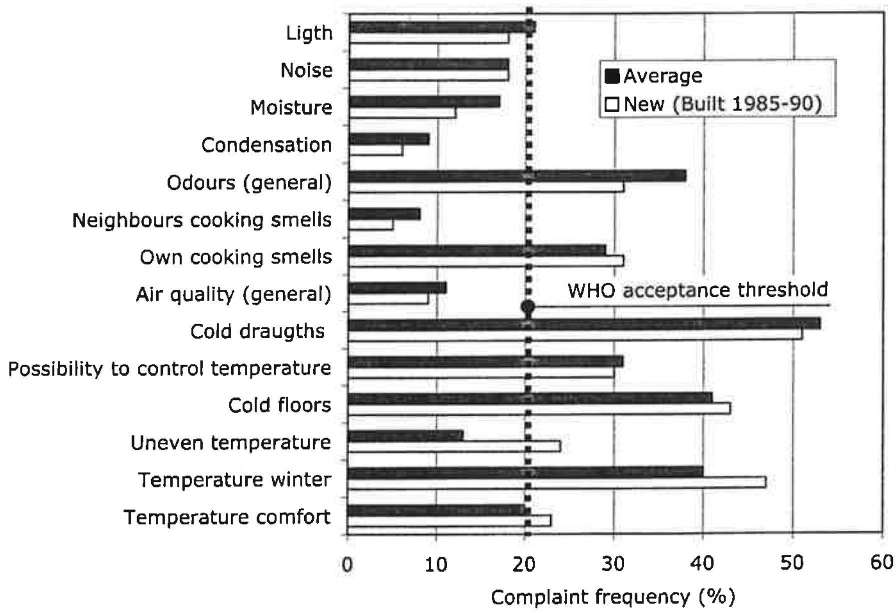

Figure 1. Complaint frequencies for residential buildings in

1.2.4 Choice of building structure and systems

The building should fulfil a number of technical functions and furthermore be economical. Some of the characteristics are restrained by public interests, for instance safety, which is addressed by building codes.
There is also influence on design decisions by a number of irrational factors. Compare figure 2, below.
The design choices should ideally lead to an optimal combination of materials and systems to reflect the long-term requirements of the specific client.

Even if the problem of bias described in figure 2 could be eliminated, there are other barriers to the optimal design choices such as:

- The client is not capable of defining, expressing and/or give priority to the functional requirements.
- The interaction between different functional requirements and between the requirements and the building structure and technical systems is complex and receive too little attention by the designers.
- The motivation for rationalisation has been weak due to the regulated market situation for residential buildings.
- The incentives for producers and designers to pursue long term qualities for the building are diffuse or non-existing.

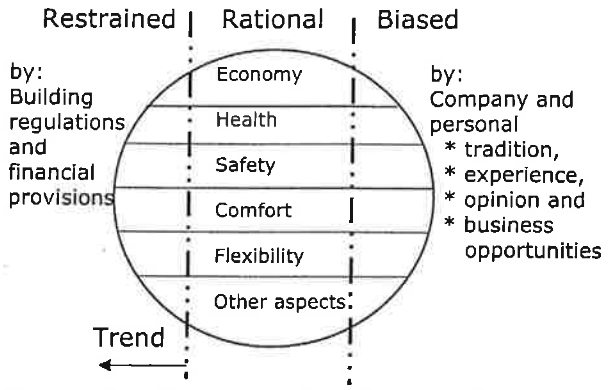

Figure 2. The basis for design decisions is not entirely rational

1.3 THE RESIDENTIAL BUILDING OF 2010

The future market for residential buildings in Sweden is, without doubt, going to be more diversified. The range of price/quality demands will be greater and the link between price and quality will be stronger. The importance of the location will however remain a prime price factor that to some extent could weaken the quality to price relation.

Regarding technical requirements the building regulations change from descriptive to functional and their scope will be strictly limited to the 'Essential requirements' of the EC building product directive.

The production process needs fundamental change and inspiration can be drawn from the lean and agile production philosophies within other industries.

The sustainability issue will influence the market by

- higher energy prices, which increases the interest for low-energy or zero-energy houses,
- better utilisation of materials, which increases the need for flexibility of components with high longevity, such as building frames, and recycling aspects of components with shorter longevity, such as surface materials and light partitions
- greater interest in lifecycle appraisal
- attention to impact of external provisions such as the local geography, topography and climate as well as the available infrastructure on the overall performance with regard to sustainability of a building.

In summary, the industry will need to be more competitive, meaning on the one hand being more adaptive to the client's requirements, and on the other being able to rationalise.

1.4 THE RESEARCH PROJECT

1.4.1 Vision

The vision of the project is that:

- The customer and/or the advisers in the pre-design stage, have the competence and information needed to define the best suited building with regard to functional, economical and aesthetic criteria over the entire life cycle and in harmony with the surrounding environment.
- The building is designed fulfilling the goals of the pre-design, adding aspects of a good building that may be not explicitly defined by the customer and providing adequate provisions for rational production.
- The building is produced with minimum effort and time to the intended quality.
-

1.4.2 Objectives

The project vision is broken down into the following objectives:

- To quantitatively survey the current construction systems for multi-storey concrete residential buildings (Function and economy), including references to any 'exterior' provisions that have to be observed, such as building regulations.
- To spot possible design process related barriers to improvements of residential buildings. Other building process related issues are not within the scope of the study.
- To visualise all the future requirements on residential buildings such as function, life cycle economy, sustainability and buildability.
- To track, and establish methods to assess and optimise, the interaction between: Functional requirements – structure – technical systems – economy. (Integrated Life Cycle Design)
- To assess possible changes in technology and design process that enhances the overall performance of residential buildings with concrete structures.
- To demonstrate the improved residential concrete building in a full scale project.

1.4.3 Research questions

The main research questions to be addressed in the project are:

- Is it possible to establish some robust engineering practise for the lifecycle appraisal of concrete buildings in the design phase?
- Which are the potential improvements regarding lifecycle performance of concrete buildings that could be achieved using a holistic design and construction approach?

1.4.4 Methods

The survey of current practise as well as mapping of requirements for the future residential building will be carried out through studies of literature and statistical data and by interviews with architects and technical consultants, contractors, material producers, owners and users.

The optimisation will be conducted by desktop studies using mainly currently available design tools. A modular approach such as presented in section 5.2, below, is envisaged.

2 ESSENTIAL FUNCTIONAL PROPERTIES

2.1 GENERAL

As a base for improvement the most fundamental properties of a residential building must be mapped, quantified and their relative importance estimated. The correspondence between these properties and their relation to the building frame and the technical systems is crucial.
In following table, see figure 3, a choice of essential functional properties that are deemed to be important are listed, and their assumed correspondence indicated. The table should is only presented as an example of the complexity of functional interaction.
It may very well be that the correspondences as well as the choice of parameters are radically changed as a result of the research project.

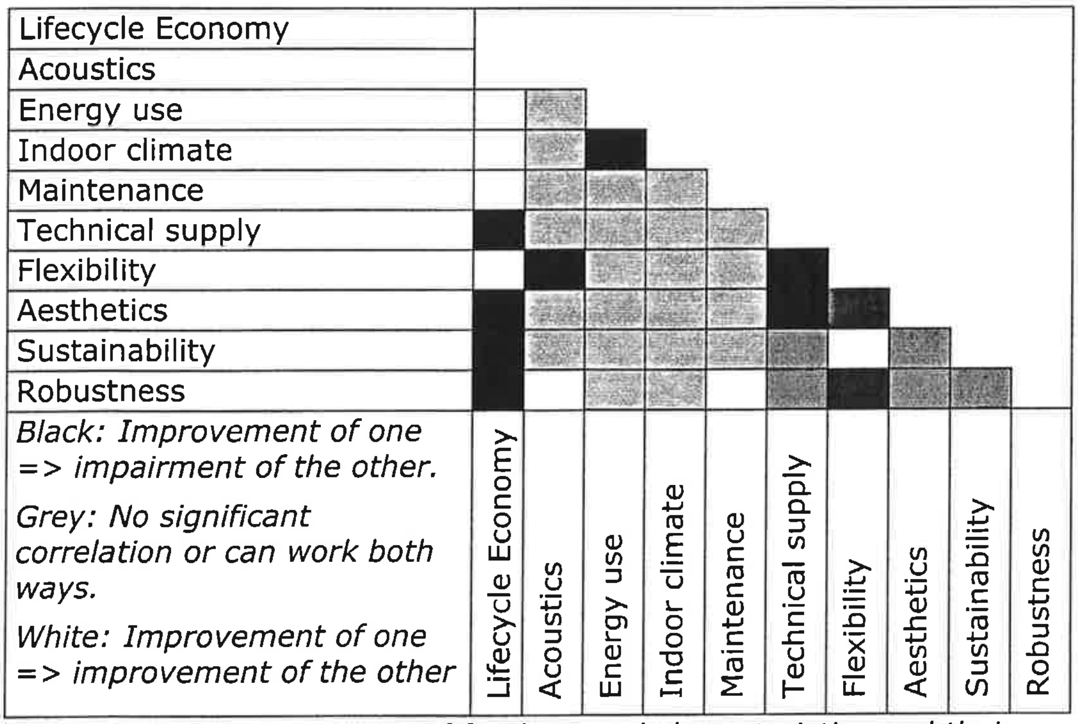

Figure 3. Tentative system of fundamental characteristics and their correspondence which will be analysed in the project.

2.2 ACOUSTICS

The important sources for noise disturbances are:

- Noise caused by human activity in other apartments or common areas within the building such as staircases and elevators
- Noise from technical systems within the building
- Noise from the outside
- Noise from within the apartment

Noise is transmitted directly through separating walls and floors or can be relayed further via the building structure or technical systems.

Figure 4, shows a typical complaint distribution regarding noise in new residential buildings. In this case built in Stockholm 1985-90. [1]

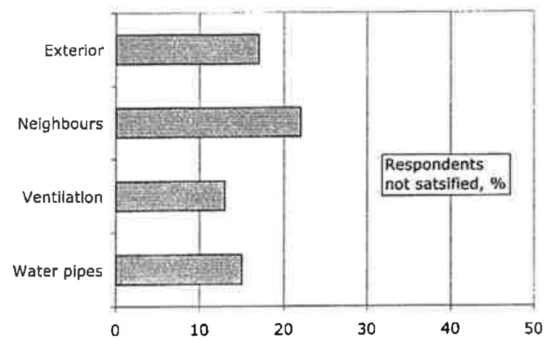

Figure 4. Noise complaint distribution in new multi-family residential buildings [1]

The new building regulations, BBR 99, [2] classify sound insulation in four levels, A to D, to which specific requirements on sound reduction, over the enveloping surfaces apply.
According to BBR99 the next lowest sound level class, C, is the minimum quality level for new residential buildings.

Good sound insulation is one of the most important quality aspects regarding residential buildings. A recent study from the Swedish National Building Research Foundation indicates that 60% of the respondents are willing to pay 200 SEK/months, and 40% 400 SEK/month, more for a quieter apartment.

The sound insulating properties of a building depends on material properties, design of partitioning structures and connections and on quality of execution.

The research project will examine the necessary technical provisions and the consequences with regard to other functional aspects and economy, to provide a certain sound insulation quality level according to BBR99 [2].

2.3 ENERGY USE

2.3.1 Research general

Energy is used through all life cycle phases from the extraction of raw materials to demolition and recycling.
The use of energy has both large environmental and economical implications. In order to form a relevant strategy for the reduction of energy consumption in buildings it is important to be aware of the relations regarding use between different phases in the process. This is displayed in table 1, which shows that the user phase is dominating. Normally multi-family residential buildings have a longer life-cycle than 50 years which emphasises the importance of the user phase even more.

	kWh/(m2x 50 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 1. Energy use over the lifecycle for a new Swedish multi-family residential concrete building in, according to Adalberth, LTH, 2000. [3]

2.3.2 The production phase

The energy use for the production of a building is distributed over extraction and production of fuel and electricity, extraction of raw materials, transport of raw materials and fuel, production of components, transport of components to building site and the construction work.

In an LCA study by Chalmers University of Technology [4], the total energy use for the production of different types of structural frames was mapped. The functional unit was 1 m^2 of building area, 'cradle to gate', including a proportion of external and interior walls, but excluding roof, foundations, surface materials and fittings.

According to this study a cast in situ concrete or steel/concrete composite frame requires roughly 430 kWh/ m^2 while a precast concrete or a light steel frame requires 390 kWh/ m^2. This indicates that the difference between the energy use regarding the production phase for structural frames based on very different materials and systems is small.

2.3.3 The user phase

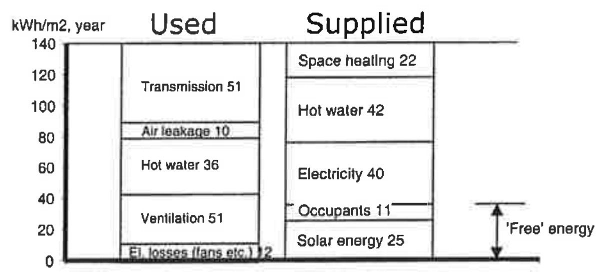

Figure 5. Example of energy balance. Multi-family residential building in Stockholm, built 1985.[5]

Using the state of the art technology regarding building and ventilation, the total energy need including heating, hot-water and electricity is 100-150 kWh/m2, year in a new multi-family residential building under average Swedish climatic conditions. A typical energy balance for a residential multi-family building is shown in figure 5. [5].

A certain amount of energy can be gained from sources other than the heating system, such as, solar energy depending on type, size and orientation of windows and energy from people and their activities. This is shown as 'Free energy in figure 5.

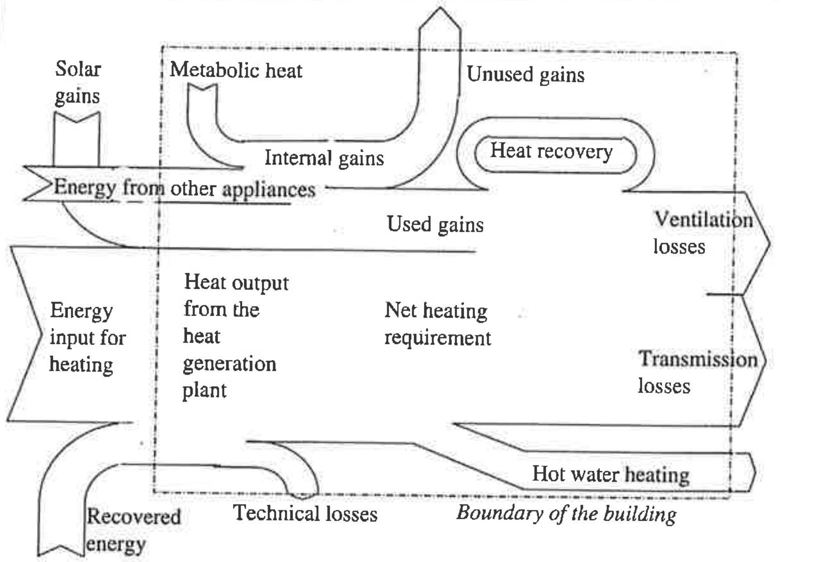

Figure 6. Energy balance for buildings according to CEN. [6] (Metabolic = from occupants)

Guidelines on energy calculations, including energy gains and thermal storage are given in the draft CEN Thermal performance standard for buildings. [6]. In this standard the energy balance of a building is displayed schematically. See figure 6.

For a residential building 5 W/ m^2 gain from people and activities is used for calculations according to the draft CEN standard. [6] Calculation of energy use for heating'. Depending on the building structure and the technical systems the energy gains from solar radiation and occupants can contribute to decrease the amount of bought energy.

It is not only the total energy input that is of interest but also the distribution between energy carriers. Special attention is required regarding the use of electricity to run technical systems for recovery of energy.
The Swedish building regulations [2] state that the mean U-value for a residential building should be equal or lower than 0,18+0,95x(Window area/Total enveloping area) W/m^2K. The requirement for air tightness is 0,8 l/s m^2 as maximum leakage through the building envelope at 50 Pa difference in air pressure.
There is also a functional opening in the regulations allowing for 30% higher mean U-value if it can be shown by calculation that the total annual energy use is not greater than for a theoretical reference house having the required mean U-value.

The research project will explore the possibilities to decrease the need for input of energy for heating, and to increase comfort by

- *defining robust technical solutions that minimise heat losses through transmission (including heat-bridges) and air leakage*
- *exploiting the interaction between surplus energy available with building structure and HVAC system (passively or actively)*

2.4 INDOOR AIR QUALITY, MOISTURE AND THERMAL COMFORT

2.4.1 General

In average 65% of our time is spent at home and additionally 20% is spent inside other buildings.

It is acknowledged that comfort, health and mental capacity are closely related to the indoor climate and that the indoor climate can, partly but not fully, be described in technically quantifiable terms.
This section includes an overview of indoor climate aspects and a description of current technical systems for heating and ventilation.

2.4.2 Temperature

The operative temperature is dependent on temperatures in the air and on surfaces in combination with air velocity. In the Swedish building regulations [2], the minimum operative temperature is set to +18 in residential space with the exception for +20 in bathrooms. The surface temperatures may vary between +16 and +27. The maximum permitted air velocity is 0,15 m/s during the heating period and otherwise 0,25 m/s.
Extreme temperatures are balanced by the capacity of materials to absorb and release heat. Besides providing better indoor comfort this mechanism also decreases the maximum effect required for the heating system and the overall energy need. Guidelines on calculation of thermal storage are given in the draft CEN Thermal performance standard for buildings. [6]

2.4.3 Humidity

The indoor air humidity affects our experience of indoor comfort, the durability of materials and biological risks, such as mould growth.
The humidity is normally larger in new buildings because of larger moisture content in new materials and the climatic conditions at the building site.
After a certain period of time the humidity will reach a certain balancing level dependent on indoor moisture sources, and ventilation. There is also a seasonal variation linked to the outdoor conditions. The variations regarding humidity is to a certain extent balanced by the hygroscopic behaviour of building materials. Materials also have different durability with regard to moisture exposure. Typically durability is reduced when moisture is increased.
The humidity is an important parameter with regard to SBS (Sick Building Syndrome). In figure 7, below, an optimal or safe, zone for relative humidity has been proposed. [7]

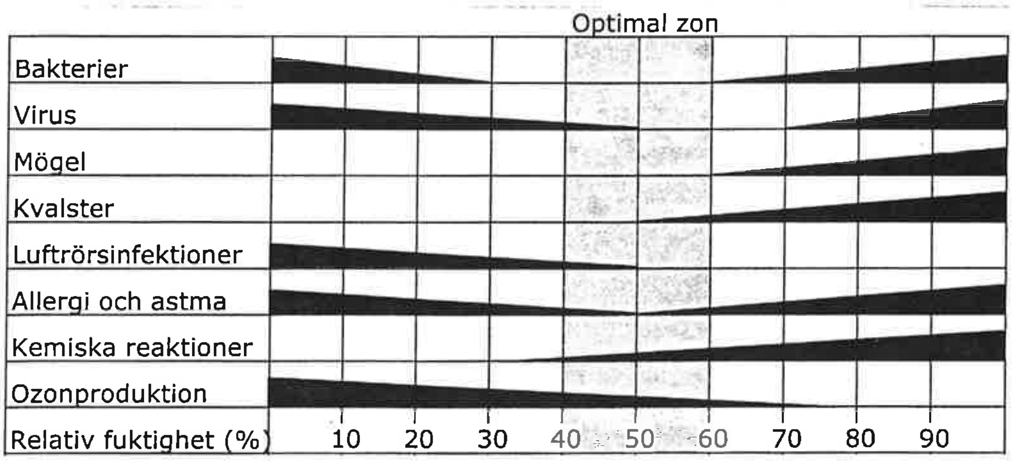

Figure 7. Optimal indoor relative humidity according to [7].
Increased height on triangles => increased risk.

2.4.4 Indoor air quality. IAQ

The concentration of different species and particles in the indoor air and their connection with sources is relatively well known. The main pollution sources are

- biological such as human exhalations, mite and mould
- outside air pollution
- emissions from materials

The measuring methods to quantify concentrations in the air (µg/m3) as well as emissions (µg/m2h) from materials are reliable. There is however a lack of knowledge between what is being measured and the symptoms on humans. There are recommendations in the building regulations and in other IAQ assessment systems with regard to maximum 'TVOC', but it is acknowledged that this is only an indicator on the amplitude of emissions and that it says nothing about the harmfulness of the particular species in question.
In the building regulations there are also requirements on minimum air exchange volumes for residential buildings. (0,35 l/s,m2. floor-area)

2.4.5 HVAC-systems in residential buildings

The heating and ventilation systems in combination with the building structure and the building envelope set the indoor climate conditions.
For new residential buildings the following systems dominate;
- Mechanical exhaust air systems, with or without energy recovery with air heat pump, in combination with hot water radiators.
- Balanced ventilation with air heat pump for energy recovery, in combination with hot water radiators.

Systems with floor heating based on hot air or water also have become available since super-insulated windows have eliminated the need for radiators placed below windows.
The systems constitute a large and expanding part of the overall production effort. The physical fitting of systems into the building is difficult and limits the flexibility in use of the building. The function of the systems tends to become more susceptible and the customer satisfaction with the indoor climate has not increased. Compare figure 1, above.

2.4.6 Air tightness

Air tightness between different flats and over the climate shell is important for various reasons.
The shielding function with regard to energy, fire, noise and odours is directly dependent on air tightness.
An air tight climate shell is thus a prerequisite to limit energy use for heating, to achieve an even ventilation rate in different rooms and finally to avoid risks for condensation of moist indoor air within the exterior wall or roof. Condensation leads to decreased function of insulation material and mould problems on organic materials. Above all buildings with balanced ventilation, but also natural ventilation, are sensitive from this point of view, because of the risk for interior over pressure in certain parts of the building.

In heavy structures such as concrete outer walls no specific measures need to be taken with regard to air tightness and the material is not susceptible to any deterioration due to moisture. Wall to floor connections, window and door fixtures and movement joints are simple to design, produce and maintain.
Within lightweight structures the air tightness is taken care of by plastic foil. Special care should be taken with regard to connections and the plastic foil should be protected from mechanical damage during the user phase. The long-term durability of plastic foil has also been questioned.

Indoor climate is a very complex and important topic and it is correlated to the aspect of energy-use. The aim of the research project is to establish robust technical solutions based on interaction between the building structure and the technical systems, that satisfies requirements of health, comfort, energy conservation, economy and flexibility.

2.5 MAINTENANCE

To support decision-making in life cycle design information of maintenance requirements for materials and systems is essential. This information can be systemised in a maintenance plan according to the example in table 2.

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 2. Example of maintenance plan. [8]

The maintenance plan is the basis for LCC and LCA simulations that should be undertaken in the design phase.

In the research project the use of maintenance plans within the building sector will be examined. Not only for residential housing but also for other sectors. Maintenance data relevant for residential buildings will be compiled. Simulations within the framework of LCC and LCA will be conducted to examine the overall economical and environmental impact of maintenance.

2.6 TECHNICAL SUPPLY

This feature contains the traditional types of technical systems as well as future developments such as IT-services and other possibilities that are referred to as intelligent houses. Also compare section 2.4 5, above.
One interesting field is the introduction of systems for individual monitoring of energy and hot water use in multi dwelling-blocks. Recent tests in some Stockholm building projects show that the energy use decreases by in average 10 to 15% in buildings where the each flat continuously can follow and is charged for their specific energy use. Individual flats decrease their energy use with as much as 50%. [9]

Within the research project concepts of the 'intelligent house' character will be scanned in order to spot items that may have some fundamental impact on the residential building sector. Regarding the basic technical systems such as HVAC- and electrical systems, compare section 2.4.5, above.

2.7 AESTHETICS

The exterior aesthetic appearance of a building is in the hands of the architect and the municipal planning authorities. There are technical possibilities within reasonable cost to provide most kinds of facade textures and colours. A lightweight building can be made looking like a 'stone house' vice versa.
The type of structural frame is therefore seldom a restriction regarding the choice of facade material. Certain facade types however logically appear together with a specific structural frame system. From a structural point of view the two different principles that can be applied are the load carrying facade or the curtain wall.

2.8 FLEXIBILITY

The interior planning possibilities and in particular the flexibility are directly linked to the system and material of the structural frame.

Flexibility is a matter of several dimensions such as
- building structures or technical systems that allows maximum freedom for adjacent systems
- possibility to rearrange interior partition walls within a flat
- possibility to rearrange the major interior plan of a building
- adaptability of the technical support systems to changes
- possibilities to increase or decrease the size of the whole building vertically or horizontally

There are two possible strategies to handle flexibility:
I To design for general flexibility. This implies a certain choice of structural and technical systems and usually a certain over capacity regarding different capacities.
II To design for a specific (predicted) future change. In this case a more exact design can be made to match the extension or change.

Flexibility is primarily a design issue. There are some important aspects that depend on the structural or technical systems chosen. The most obvious is long floor spans which allows freedom with regard to positioning of interior walls and thus freedom with regard to sizes of flats and rooms. Compare figure 8, below.

The objective of the project with regard to flexibility is to
- *define reasonable general flexibility with regard to structure and installations*
- *seek and evaluate design measures to ensure this flexibility (concentrating on concrete structures)*

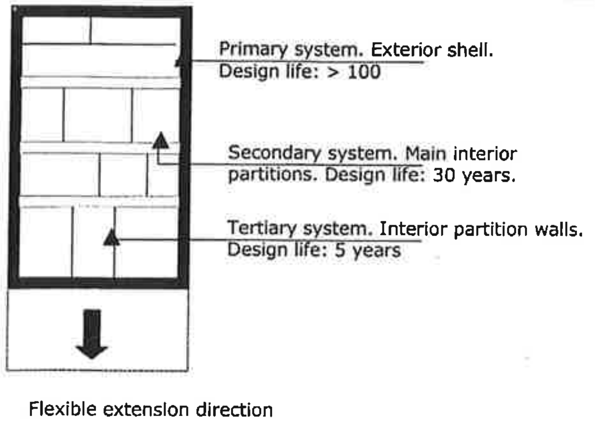

Figure 8. Principles of life cycle design

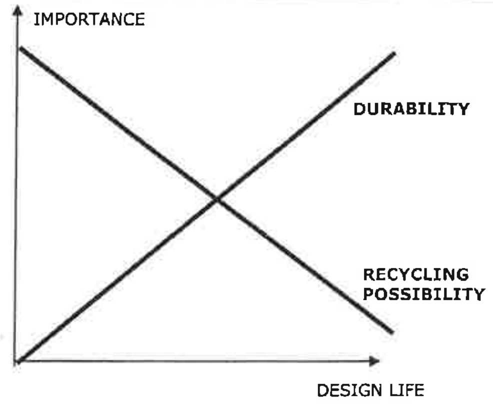

Figure 9. Principles for optimisation with regard to design life

2.9 SUSTAINABILITY

The first International Conference on Sustainable Construction. 1994, defined sustainable construction as:
'The creation and responsible maintenance of healthy built environment, based on ecological principles, and by means of an efficient use of resources'.
This summarises most of the essential functional characteristics that are discussed in this paper such as energy use, indoor climate and flexibility and is addressed by the fundamental idea of this project: To use holistic considerations for the building as a system over the entire life cycle.

One important aspect for sustainability as well as life cycle economy is to consider the design life for the different structures and systems that constitute the building. 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 'Industrins Byggmaterialgrupp'. [10]

In figure 8, the principles for life cycle design are displayed, and in figure 9 some implications regarding durability and recycling aspects are presented.

The aim of the project with regard to sustainability is to identify and apply systematic life cycle design criteria.

2.10 ROBUSTNESS

Robustness represents the ability for materials, structures and systems to withstand wear, damage and regular as well as accidental or unintended loads.
The resistance to regular wear and environmental exposure conditions is referred to as maintenance, which is dealt with in section 2.5, above. Structural behaviour (vibrations and deformations) with regard to service loads depends on the material properties and the structural design. For

concrete residential buildings the service life structural behaviour is favourable and needs no particular attention.
The remaining issues are primarily

- mechanical damage caused by people
- water-damage (leakage of water)
- fire

In multi-dwelling blocks severer mechanical damage is primarily concentrated to common and accessible areas such as stairways, basements and street level facades.

Fire safety in a building is dependent on

- the ability to keep a fire within a confined area
- fire resistance of load carrying and stabilising structures
- the materials behaviour regarding ignition, combustibility and build-up of smoke
- escape possibilities
- fire alarm systems
- availability of active fire protection devices such as sprinklers. (Such systems are normally not used within residential buildings)

The level of fire safety of a building is classified in three levels according to the building regulations. [2]. The highest safety level, Br 1, is applicable for three storey buildings and higher.
The classification of fire resistance for a structure is composed by: R (load carrying capacity), E (integrity) and I (insulation) followed by the time, expressed in minutes, that the component will withstand a standard fire.
For the confinement of fires a building is divided into fire cells. In a residential building a fire cell typically is one flat.
A structure separating fire cells in a residential building with the fire safety class Br1 must have a fire resistance not less than EI 60. Also facades are regarded as being part of the fire cell confinement. Regarding load carrying capacity for structural and stabilising components the requirement is R60, R90 or R120 for residential buildings depending on number of floors in the building and type of structure.
In figure 10 typical sections of wall structures satisfying classes REI 60 are displayed.

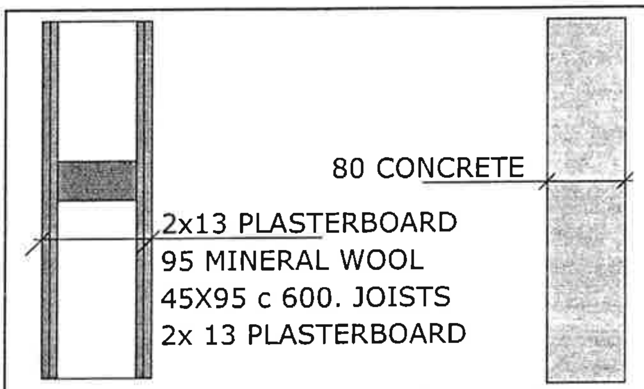

Figure 10. Examples of walls satisfying REI 60

Damage by water has a certain similarity with fires in that the total extent other damage depends on the ability of the structure to confine the spread of water. The severity of the damage is of course also connected to the material properties with regard to being damaged by water.

In the research project the costs for different categories of damages will be analysed with the help of statistics from insurance companies and large owners.
Some type of expanded total risk classification for different types of technical solutions incorporating or complementing the existing classification for fire resistance will be pursued. The technical and economical consequences for moving between the different risk levels will be mapped.

3 ECONOMY

3.1 LIFE CYCLE ECONOMY - GENERAL

The life cycle economy of a residential building consists of costs such as production costs, operating cost, financial costs and some less well-defined cost to take care of the building after its lifetime and of revenues, i.e. rents.

The functional properties of the building influence the economy in two different ways:
I Directly. Example: Energy use is directly correspondent to the operating cost.
II Indirectly. Example: The rent for a safe and comfortable flat should be higher than the less safe and comfortable one. 'Life Cycle Revenue'

It is acknowledged that the correspondence between quality and price has been, and to a large extent still is diffuse which has been commented on in section 1.2.1, above. In the future more diversified housing market the price/performance relation is expected to become more distinct.

Relevant assumptions regarding operating costs as well as life cycle revenues dependent on customer value, are fundamental for the holistic approach.

3.2 PRODUCTION COSTS

Municipal fees, site costs, design costs, cost for the construction work and materials, cost for the technical systems and taxes compose the production costs for residential buildings.

The research project will analyse production costs for residential buildings. Cost differences between structural and technical systems will be examined. Matters that influence the production costs such as relationships between production time and production cost will be studied.
This work will be conducted in co-operation with contractors experienced in all current production methods
Methods according to 'Supply-Chain-Management', [11], principles will be used, in which every step in the production chain will be looked at with regard to time use, capital use, value generated, waste produced and risk.

3.3 OPERATING COSTS

The direct operating costs are built up by primarily heating, electricity, cleaning and maintenance.

The research project will analyse the distribution of operating costs, their variations and seek links between the costs and type of building structure and technical systems. This will be achieved through interviews with owners and generally available statistics.

4 THE BUILDING PROCESS

It is generally recognised that the building process suffers from some drawbacks when compared to other industries. The market for residential buildings is no exception to this with its particular struggle to get out of the state interference on top of the other building process-related shortcomings.
The problems could be categorised in 'non-value generating activities' and 'design-build and run away problems'. The following list indicate some of the dominant issues:

A A lot of non-value adding effort is spent on the procurement and assessment of the works.

B The lowest bid (production cost) principle does not encourage holistic thinking.

C Every actor in the fragmentised process is programmed to guard their know how rather than sharing it. This is a barrier to evolution.

D The distance between designers and producers on the one side and the client or the user on the other, is large. The relation between cost and customer value is therefore weak. The client involvement in general is weak.

This project focuses is on the function to design area. Thus in particular item D and partially also items B and C will be addressed.

The planning and design process will have to be reorganised and strengthened. The design process of today is normally loosely held together and the different specialists strive to optimise their particular contribution rather than to consider the entity. Often the lifecycle perspective is also neglected.
A parallel can be drawn from the auto-industry: In the traditional western mass-production system the project leader for development projects, such as a new car model, is only a co-ordinator that struggles to bring together different components and systems that have been more or less independently designed.
Within the Japanese lean-production philosophy the leader of the development project, which corresponds to the design process of a new building, is one of the most powerful and respected positions within the whole company. The Japanese denotation for this role is 'SHUSA'. [12] The SHUSA is responsible for

- the functional performance of the product,
- production aspects to be taken into account and
- bringing in the know how of all design team members and suppliers.

The Japanese system has invariably led to shorter developing time, more rational production and better products than the traditional western mass production.

One possible way of developing the design process would be to apply the SHUSA-concept to reinforce the role of the design management. Compare figure 11, which is a development from a figure in the Competitive building - Programme Plan. [13] This function could be held by one of the members of the team, such as the architect or the structural engineer or could be placed as a specific function. The difference to current practise is the scope of responsibility and authority, which is laid upon this management role.

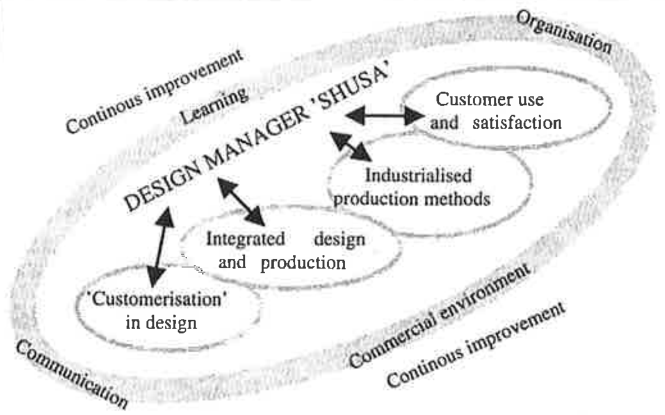

Figure 11. The design manager at the steering wheel. Derived from [12,13]

Some of the lean production principles have been practised with encouraging results within the so-called 'Svedalamodellen' [14]. Co-operation and openness between the project partners, precise objectives and active participation from the client has contributed to comparably low rent levels. [15]. Another example studied by 'Byggkostnadsdelegationen', Wigral 2, in Ängelholm, confirms the improvement potential. [16].

The research project will examine the necessary changes with regard to the organisation of the design process that will be needed to enable integrated life cycle design and the possible consequences this will bring to the entire building process.

5 INTEGRATED LIFE CYCLE DESIGN

5.1 GENERAL

There is a wide range of functional requirements for a building, as has been discussed above. Furthermore there are economical and environmental considerations to be addressed. To complicate the problem the different aspects usually interact with each other. The planning and design phases dictate the customer value that can be achieved. Poor execution can ruin the result of good design but superb execution can only slightly improve a poorly planned and designed building.

In order to facilitate holistic decision-making in planning and design, or 'integrated life cycle design', there are three components necessary:

- specifications of technical, economical and environmental performance requirements
- methods for the analysis of individual functional aspects
- a method for multiple criteria decision making and optimisation

The specification is a very familiar instrument within the building industry. There are however two general aspects that could be developed:

- the requirements should be transferred from descriptive to functional to a greater extent than is the case today
- the economical and environmental consequences of the choice of requirement level over the entire life cycle should be made visual in a more distinct way and the client should be encouraged to include such criteria in the specification

Regarding the technical contents of the specifications there are still some important areas that need further knowledge, such as indoor air quality.

The *methods for analysis of individual functional* aspects are more or less available today. Adequate tools for safety-, structural and durability design are at hand while for instance ecological design still must be regarded with some scepticism.

Methods for *multiple criteria decision making and optimisation for life cycle design* of buildings are still only prototypes. The use of new modular and interactive design procedures, are needed.

5.2 THE METHODOLOGY OF LIFE CYCLE DESIGN

To tackle the complex situation with several more or less interrelated functional requirements some kind of modular approach is convenient. In figure 12, Professor Asko Sarja proposes a framework for integrated design. [17]. The two main features of the framework are the definition of requirements and the design.
The definition phase requires tight co-operation between the client and the design team. Special attention should be paid to the balance between customisation for the initial application and the generality of the building.

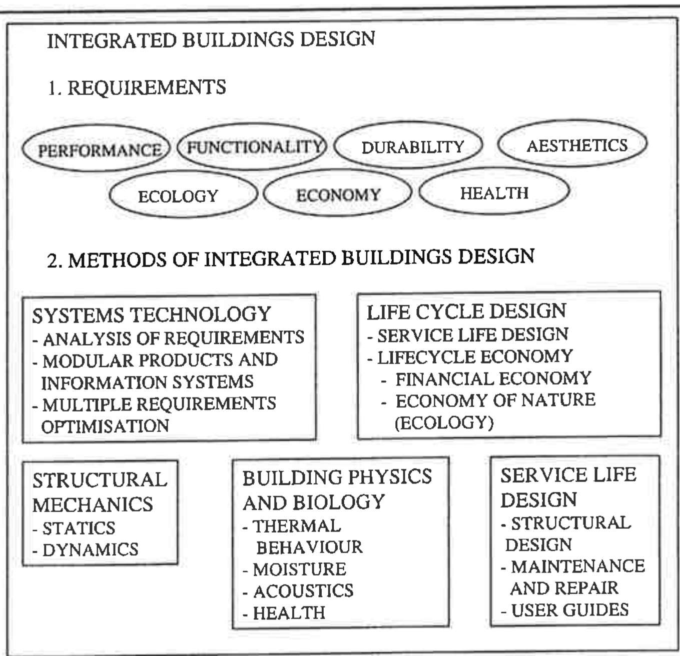

Figure 12. Framework for integrated design according to Sarja [17]

The design phase is a complex optimisation process that Saarja has grouped into five interacting modules. Each specific topic is with some exception well known and can be treated with reasonable accuracy with the available engineering tools. Putting the criteria together is the core of this research project.

The aim of the research project is to develop and launch a system for integrated life cycle design. Methodology from other problem areas regarding multi criteria decision making and optimisation will be examined and a modular approach as presented in figure 12, above, is envisaged.

5.3 LIFE CYCLE DESIGN - SIMPLIFIED TOOL

There is a common complaint about weak client involvement in the building process. This is sometimes blamed on ignorance on the client side. In reality the client knows very well that the building should have an attractive appearance, be quiet, have good indoor climate, be ready to move in to at a certain date and so on. The client also knows that the building should have reasonable production costs and operating costs. The problem arises when
A Different functional aspects interact in a diffuse way
B The link between life cycle economy and design choices are weak
C Different experts struggle to optimise their tasks within the project without having any distinct guidance on functional priorities and usually with exaggerated focus on production costs.

Looking at other types of products it is evident that many clients are prepared to pay an initially higher price if it can be assured that a certain extra quality will be added. This should be taken into account by the building industry.

Aspect	Base Level	Effect on total LCE % per class	Choice	Effect on LCE	Comments LCE = Life Cycle Economy
Acoustics Performance class According to BBR 99 A, B, C, (D)	C	3	B	1,03	Where accepted performance classes are available it is easy to establish a weighting system
Flexibility * Performance class F1, F2, F3	F2	-2	F1	0,98	Classes must be developed
Aesthetics ** Classes A1, A2, A3	A2	3	A2	1,00	Classes must be developed

Table 3. Conceptual model for a holistic evaluation of different aspects.
** How should LCE be calculated? If the building will be changed the LCE will of course be favourable for the building which originally designed for flexibility otherwise less so! A prediction must be made.*
*** It is obviously not so easy to define classes for aspects that contain some subjective feature.*

In table 3, above, one kind systematic approach is envisaged and some of the problems connected with this is commented on. Ideas could be borrowed from for instance the impact assessment step within environmental life cycle assessment. In this case life cycle economy is chosen as the optimisation key. It should be stressed that this is a proxy parameter that can reflect any important aspects that are given arbitrary weights (importance) according to the specific project.

The aim of the research project is to seek a simplified tool by:

- *describing each essential functional in terms of quality levels or classes to make a logical choice possible*
- *finding keys between the quality levels and the economical and ecological consequences to support simulations and choices*
- *introducing some common denominator or 'currency' that makes it possible to compare the different functional requirements*

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