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Building Cost Model

Modèle de calcul des coûts de construction

Baukostenmodell

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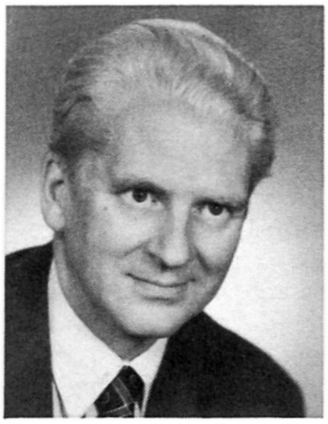

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SUMMARY

The paper describes a building cost model which can be used at the early design stage when costs can be most effectively controlled. «Steering» the main areas, the *Grobflächen*, is introduced so that the most favourable combination of *Grobflächen* can be selected, resulting in the lowest costs. The various *Grobflächen* are given a price tag per m², which can be used as part of a weighting system for the corresponding areas. Investment and future costs are taken into consideration. Only those costs that the designer can influence are taken into account.

RÉSUMÉ

L'article propose un modèle de calcul des coûts de construction qui peut être utilisé au stade du projet où les coûts sont plus facilement maîtrisables. Il introduit un système de régulation des surfaces principales, appelées *«Grobflächen»*, autorisant le choix de la combinaison de surfaces la plus économique. Les diverses *«Grobflächen»* se voient attribuer un prix au m² qui permet le calcul pondéré du coût de chacune d'elles; le modèle tient compte des coûts d'investissement et des coûts futurs, et ne prend en considération que les coûts qui peuvent être influencés par le projeteur.

ZUSAMMENFASSUNG

Die Studie stellt ein Baukostenmodell vor, das in der frühen Planungsphase, wenn die Kosten am wirksamsten beeinflusst werden können, einzusetzen ist. Die Lenkung der Grobflächen wird eingeführt. Die vorteilhafteste Flächenkombination wird angestrebt, um die niedrigsten Kosten zu erzielen. Die Kosten pro m² Grobfläche werden festgelegt, was einer spezifischen Kostengewichtung der Flächen gleichkommt. Sowohl Bau- als auch Folgekosten werden berücksichtigt. Nur Kosten, die der Planer beeinflussen kann, werden in Betracht gezogen.

THE COST GEOMETRY OF BUILDINGS

It is generally accepted that the geometry of a building has an impact on costs. The relative proportions of areas have been used as tools for analysis, and some authors [2], [3] and [4] have given further thought to the question.

In 1987, the Swedish Council for Building Research decided to promote a study, the report on which presents a system with the following characteristics:

- It can be used at the early design stage, when costs can be most effectively influenced;
- It establishes the closest possible connection between costs and cost-generating factors;
- It can be used manually, which means that the procedure is transparent. Changes in the model can readily be made by the user, who can at an early stage take decisions to optimize the design without resorting to outside cost expertise;
- The "steering" of areas is introduced. The areas in question are those that can be identified at the early design stage, and an optimum can be reached by choosing the most economic combination of areas. To facilitate this, a cost weighting is assigned to each area in question, expressed, in this case, in Swedish crowns (later called "crowns") per m² of external wall, for example;
- Investment and future costs are treated, which means that a decision can be based either on the investment or on the life-cycle cost;
- Only those future costs are taken into account that can be influenced by the designer. However, it would also be necessary to consider costs that are at present paid by others but that will probably be charged to the project in future, e.g. certain environmental costs.

It is essential to take cost considerations into account as early as possible in the design stage. This is demonstrated by the oft-quoted "possibility curve".

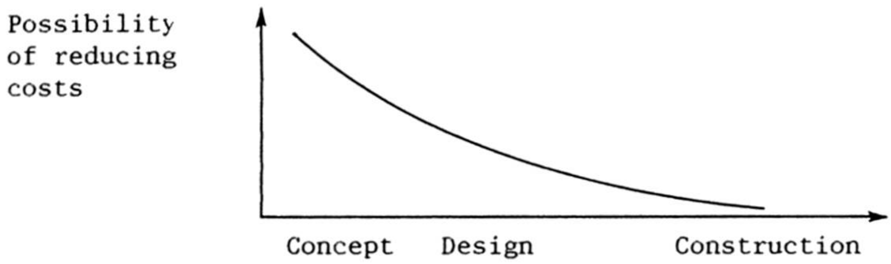

Figure 1. The possibility of reducing costs at various project stages.

The curve is in reality made up of discontinuous steps, reflecting the relevant decisions taken during the process.

The cost geometry technique addresses itself to the early design stage. The basic idea is that costs (C) can be attributed to finite quantities (Q) that can be measured or estimated at the early design stage.

$$C = f \quad (Q)$$

Costs are taken here to mean either investment or life-cycle costs (LCC). As a first step, we shall deal with areas (A) and assume that there is a linear relationship between (C) and (A).

$$C = k \cdot A$$

The areas referred to are the Grobflächen (= basic elements), a concept introduced by the Architektenkammer Baden-Württemberg and defined as roof area, external wall area, horizontal dividing area, internal wall area and base area.

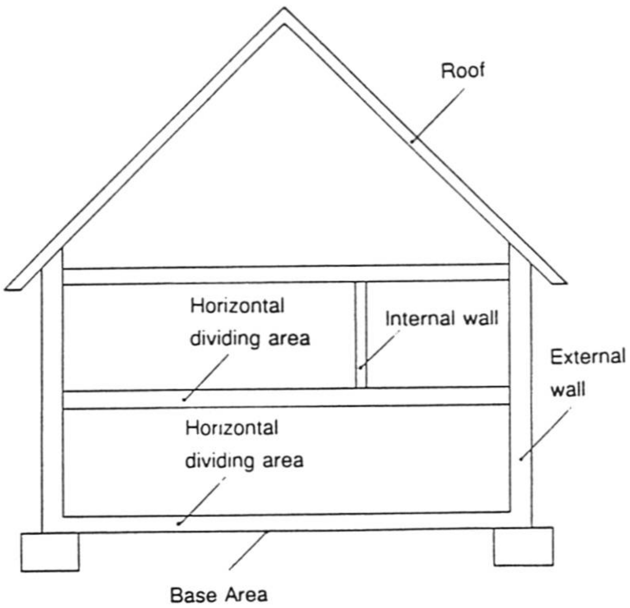

Figure 2. The Grobflächen.

To demonstrate the principle, let us take a roof with an area of 2,050 m², for which the investment is 840 Swedish crowns per m².

$$C = 840 \cdot 2{,}050 = 1.7 \text{ million crowns}$$

The investments for the other Grobflächen are calculated in the same way.

Roof	840 crowns/m² • 2,050 m² =	1.7 million crowns
External wall	1,750 crowns/m² • 3,200 m² =	5.6 million crowns
Horizontal dividing area	820 crowns/m² • 6,600 m² =	5.4 million crowns
Internal wall	780 crowns/m² • 4,730 m² =	3.7 million crowns
Base area	1,200 crowns/m² • 2,135 m² =	2.6 million crowns
Total for the above investments		19.0 million crowns

Table 1. Investments per Grobfläche.

Let us now consider future costs, which are calculated for a life cycle of 60 years. The discount factors used are based on a real interest rate of 4%. The costs are assumed to be related to the Grobflächen and are expressed in 1,000 crowns per m² of their area. The corresponding investment data have been added. The data for the horizontal dividing area have been broken down into net usable floor area, communication area, "hygienic" area (e.g. toilets), and other areas.

Grobflächen	Invest-ment	Heating energy	Cleaning	Main-tenance	LCC
Roof	840	100		300	1,240
External wall	1,750	450	1,050	800	4,050
Horizontal dividing area:					
Usable floor area	880		900	370	2,150
Communication area	1,860		2,410	450	4,720
"Hygienic" area	4,210		13,500	3,450	21,160
Other areas	590		200	60	850
Internal wall	780		450	400	1,630
Base area	1,200				1,200

Table 2. Investment, future costs and LCC of Grobflächen in crowns/m².

The "hygienic" area costs include costs for water and sanitary installations. The specific costs for both investment and LCC quoted in Table 2 are significantly higher for the external wall, the communication area and the "hygienic" area than for other areas. The data in Table 2 can be regarded as the cost weightings per m² of each of the areas considered. Elsewhere in cost geometry presentations, only ratios in m² between the areas have been considered.

Grobflächen	Investment	Heating energy	Cleaning	Maintenance	LCC
Roof	68	8		24	100
External wall	43	11	26	20	100
Horizontal dividing area:					
Usable floor area	41		42	17	100
Communication area	39		51	10	100
"Hygienic" area	20		64	16	100
Other areas	69		24	7	100
Internal wall	48		28	24	100
Base area	100				100

Table 3. Investment, future costs and LCC of Grobflächen as percentages of LCC.

The data are generated from the elements of a Grobfläche, taking the word "elements" in the sense used by Quantity Surveyors (BCIS). This is illustrated in Figure 3 for an external wall.

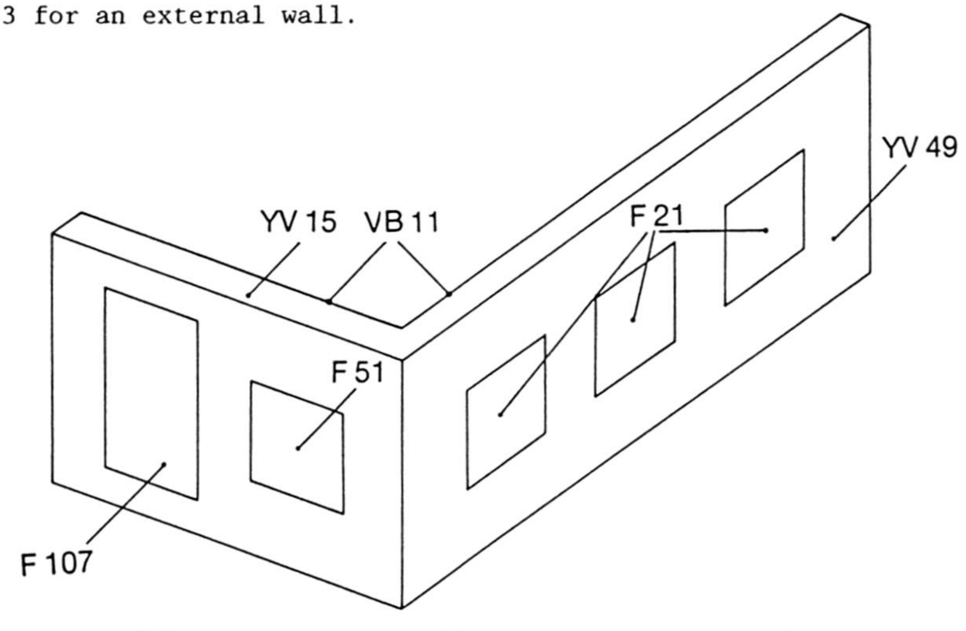

Figure 3. Grobfläche: external wall and corresponding elements.

The elements are those used by the Schweizerische Zentralstelle für Baurationalisierung, CRB [7]. Separate designations are used in the study for each of the 11 kinds of element illustrated in Figure 4.

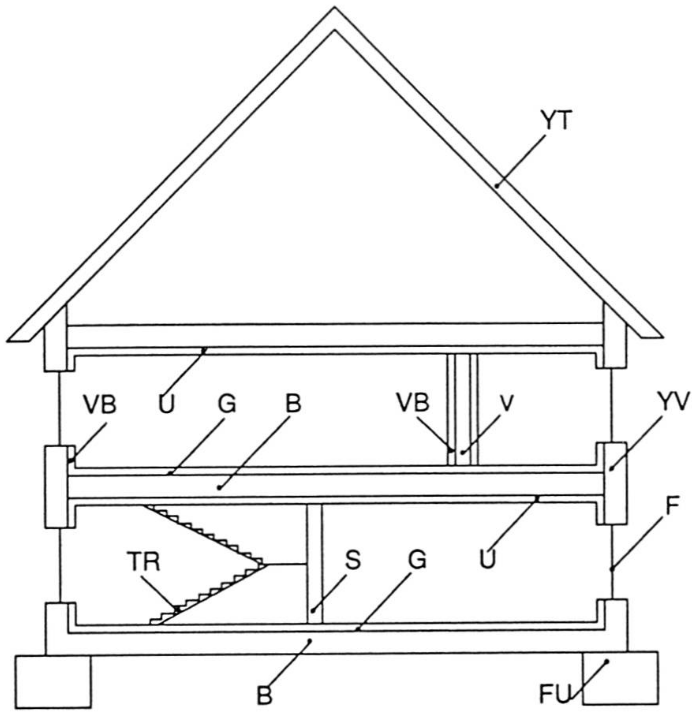

Figure 4. Illustration of the elements used.

There may be numerous types of each element, each one distinguished by a serial number following the code, which has only a mnemonic function. Each type has a homogeneous design, which facilitates the calculation of both investment and future costs. Furthermore, no mention need be made of quality since performance is tied to design. The quality of a basic element is defined by the types of elements used and by their quantitative occurrence in the Grobfläche. Hence, subjective quality judgements are avoided.

The data in Table 4 illustrate the calculation method for an external wall Grobfläche.

Grobfläche or element			Quantity	Unit	Investment Crowns per unit	Investment Total 000	LCC Crowns per unit	LCC Total 000
External wall			3,200	m²	1,753	5,611	4,068	13,016
YV	1	External wall, under earth	750	m²	1,200	900	1,500	1,125
YV	72	External wall, load-bearing	1,450	m²	1,500	2,175	1,850	2,683
YV	31	External wall, non-load-bearing	350	m²	800	280	1,350	472
F	3	Window	350	m²	3,000	1,050	8,000	2,800
F	12	Glazed wall	300	m²	3,300	990	16,400	4,920
VB	1	Wall finish, inside	3,200	m²	50	160	300	960
P	1	Column	160	m	350	56	350	56

Table 4. The generation of cost data for a Grobfläche (external wall).

The LCC per unit mentioned are taken from the specifications for each type of element. The costs derived from these specifications are broken down into investment, heating energy, electrical energy, cleaning and maintenance, where applicable, see Table 5.

External wall		Unit	Cost per unit			LCC
			Investment	Heating energy	Maintenance	
YV 1	Wall under earth, load-bearing	m^2	1,200	150	150	1,500
YV 42	Wooden wall, load-bearing	m^2	1,500	150	500	2,150
YV 72	Brick wall, load-bearing	m^2	1,500	150	200	1,850
YV 31	Corrugated sheet wall, non-load-bearing	m^2	800	150	400	1,350
YV 71	Brick wall, non-load-bearing	m^2	1,000	150	200	1,350

Table 5. Cost data in crowns per unit for various types of external wall elements.

The element could be regarded as a switchbox between the Grobfläche and the units used for the detailed cost calculation. This is important for progressive cost control and for the generation of up-to-date costs for Grobflächen.

All costs are shown at present value, the discount rates used being 2% for energy and maintenance and 4% for cleaning.

The point of departure in choosing these rates was the real interest rate, assumed to be 4%. This rate was reduced for increases beyond normal inflation. The reduction rate for thermal energy is difficult to establish as prices are not tied to production costs. In line with other Swedish presentations, a reduction of 2% has been used. A higher reduction should probably be used for electricity, but Swedish statistics do not indicate that. For maintenance, a 2% reduction seems to be justified. A different approach is taken with regard to cleaning. As a product, cleaning is not well defined, so that caution should be exercised. One possibility is simply to apply the real interest rate, thus reducing the weight assigned to cleaning in the calculation model.

It is appreciated, however, that opinions will differ as to the discounting technique. A sensitivity analysis showing the impact of a shorter life cycle and of various discount rates has been carried out. Shock increases of energy prices have also been considered. The system is transparent, which facilitates such investigations.

Our description of the system has now reached such a stage that we can go back to a statement in the introduction: "An optimum can be reached by choosing the most economic combination of areas". In effect, a steering system has been created that has the characteristic that a decrease in the areas of Grobflächen will lead to decreases in investment and future costs.

Decrease in area
leads to
Decreased investment   Decreased future costs

There is at this stage no conflict between investment and future costs. This conflict becomes apparent when, later in the design process, a design change is undertaken. At that stage, we can normally only realize lower future costs through an increased investment.

We have so far dealt only with the Grobflächen. There are, however, "other construction" costs which cannot be related to the Grobflächen and there are the costs for installations. Table 6 shows the total picture for the specific office building investigated. It should be noted that the only costs included are those that the designer can influence.

Grobfläche	Investment	Heating energy	Electrical energy	Cleaning	Maintenance	LCC
Roof	1,730	188			625	2,543
External wall	5,611	1,358		3,404	2,643	13,016
Horizontal dividing area	5,422	308		5.711	1,703	13,144
Internal wall	3,672			2,071	1.967	7,710
Base area	2,599					2,599
Costs unrelated to Grobfläche:						
Construction	1,600				800	2,400
Installations						
Electrical, excl. lighting	2,000				2,000	4,000
Lighting	1,600		2,880		3,840	8,320
Water and sanitary	280				248	528
Heating	1,200		160		960	2,320
Cooling	220		220		220	660
Air treatment	2,000	2,800	1,480		1,320	7,600
Lift	380		60		300	740
	28,314	4,654	4,800	11,186	16,626	65,580

Table 6. Life-cycle costs for an office building in thousand crowns.

This table is revealing in that it shows the considerable impact of installations, especially on future costs. We tried to trace "finite quantities" (Q) which could influence the installation costs but were not able to incorporate any into a calculation model. Data for more than 100 buildings [9], [1] were examined, without success. This is evidently a field for exploration, all the more so as the geometry of a building obviously has an impact on the installations. There is a synergy effect. Fenestration, lighting, heating and cooling have to be treated together, see [5]. The problem is that there is a lack of easy-to-use design methods. Selkowitz [8] stresses this in the context of daylighting designs.

It is, however, essential to start with a simple model in order to win acceptance from designers. This does not preclude a development that is especially called for in the installation area.

Finally, some comments on how to use the model. Measuring the areas considered at the early design stage ought not to be complicated, at least as far as the external wall, roof, horizontal dividing area and base area are concerned. The approach could then be to use relative values, e.g. assume that the sizes of the external and internal walls are the same. A word of caution should, however, be voiced at this point. Studies of ratios display considerable variations. A solution might be to classify buildings into types so as to obtain smaller variations in the ratios. For windows, one will have to start with a ratio between the external wall (NB not the floor area) and a particular window design. For the time being, the most difficult task is estimating investment and future costs for installations.

Grobfläche	Invest-ment	Heating energy	Electrical energy	Cleaning	Main-tenance	LCC
Roof	26	3			10	39
External wall	85	21		52	40	198
Horizontal dividing area	82	5		87	26	200
Internal wall	56			32	30	118
Base area	40					40
Costs unrelated to Grobfläche:						
Construction	25				12	37
Installations						
Electrical, excl. lighting	30				31	61
Lighting	24		44		59	127
Water and sanitary	4				4	8
Heating	18		2		15	35
Cooling	4		3		3	10
Air treatment	30	43	23		20	116
Lift	6		1		4	11
	430	72	73	171	254	1,000

Table 7. Life-cycle costs for an office building in per mille of total LCC.

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