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Impact on Total Costs and Construction Period of Residential Buildings in Prague

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Abstract. Optimization is a common and very often necessary process performed for economic reasons during the realization of construction projects. This report presents the optimization of a residential project at the beginning of the construction process. It describes detailed modifications made to concrete reinforcement construction that have brought cost savings, while at the same time taking into consideration the risks and costs that result from project modification.

1. Project description

The discussed residential area is located on the outskirts of Prague and comprises a set of three residential buildings with a common basement. It is thus one single structure; whose parts are operationally inseparable. The one six-storey and two five-storey buildings are designed to contain 58 housing units ranging in size from 2 rooms + kitchenette to 4 rooms + kitchenette. The basement houses technical rooms, cellar compartments and 64 parking spaces. The total amount invested in the project is approximately 4.38 mil. EUR.

The buildings are approximately square, with ground plan dimensions of 20 x 20m, and feature a receding top floor whose apartments open onto terraces. The common basement is U-shaped and covers an area of 70x70m.

The buildings stand on reinforced concrete piles. The common basement is built from a monolithic reinforced concrete structure made of watertight concrete (using the “white tank” principle). The load-bearing structure of the above-ground floors comprises a monolithic reinforced concrete skeleton filled with ceramic masonry. The buildings are covered with a single-layer flat roof with a main waterproofing layer made of bituminous membranes. The roofs of the main buildings are non-walkable, while the roof above the garages is vegetative and the terraces on the ground and top floors are provided with concrete pavement. The building is insulated with mineral wool. The atrium of the building is designed with a children's playground, paved areas and small architectural elements.

2. Original work plan

At the start of the preparations to produce the project, the construction conditions appeared to be very favourable. The planned construction period was agreed to be 16 months. Earthworks were excavated and the foundation of the building built in the months of February and March. In April, work was started on the monolithic structures. The load-bearing structure, including masonry, was planned to be complete by October. By the end of November, the building was to be sealed and protected from external weather events (via the completed roof cladding and terraces, thermal insulation system,



windows and doors). Work on the distribution systems for technical building equipment and associated construction production activities was to start in the last quarter of 2014, taking place in what was now a sealed, heated building, [1, 2]. Finishing work was to be carried out during the spring months. Finally, in the third quarter of 2015 at the latest, the building was to be approved for use, any faults removed and then handed over to the client and future owners.

Postup práce	Leden 2014	Únor 2014	Březen 2014	Duben 2014	Květen 2014	Červen 2014	Červenec 2014	Srpen 2014	Září 2014	Říjen 2014	Listopad 2014	Prosinec 2014	Leden 2015	Únor 2015	Březen 2015	Duben 2015	Květen 2015	Červen 2015	Červenec 2015	Srpen 2015	Září 2015	Říjen 2015	Listopad 2015	Prosinec 2015	
1 Zemní práce, piloty																									
2 Základová deska																									
3 Monolitické konstrukce																									
4 Zděné konstrukce																									
5 Příčky, vyzdívky																									
6 Vyplně otvorů																									
7 Střešní plášť																									
8 Kontaktní zateplovací systém																									
9 ZTI, ÚT, Elektroinstalace, VZT																									
10 Omítky																									
11 Betonové podlahy																									
12 Obklady, dlažby																									
13 Kompletace																									
14 Dveře, Laminátové podlahy																									
15 Kolaudace, předání díla																									
16 Odstranění vad a nedodělků																									

Figure 1. Schedule according to the works contract

3. Financial calculation

After the financial analysis and estimates had been performed, however, it was found that in the section of monolithic constructions there was a loss of -6.7% of the budget costs for the load-bearing structure of the building (amounting to about 1.15 million EUR). The largest share in this deficit was held by the concrete reinforcement: 125 kg/m³ of concrete was proposed in the tender documentation, but the actual tonnage of concrete reinforcement according to workshop documentation was higher. The greatest difference was found in the foundations and horizontal structures. In the tender documentation, the concrete tonnage allocated to the reinforcement in the foundation structures was 129 kg/m³, while 159 kg/m³ was stated in the construction documentation. The reinforcement in the horizontal structures also increased by 30 kg/m³ (from the assumed 109 kg/m³ to 139 kg/m³).

The expected profit from the remaining buildings was not high enough to cover the loss. Several business meetings followed with the aim of finding a solution to this problem. The client offered a solution to the contractor that involved the optimization of the project. The contractor was to examine the options for attaining savings and adjust the design solution so that the implementation costs were reduced while meeting all the technical requirements for the final shape and function of the building. The contractor accepted this offer and began to look for savings, focusing in particular on the load-bearing structure of the building. The original solution was a reinforced concrete monolithic skeleton filled with ceramic masonry. A more economical solution was designed featuring a combination of monolithic reinforced concrete walls and supporting walls made from ceramic masonry. The contractor approached the design and structural engineering office, which, after studying the project, guaranteed a minimum saving of 5.0% on the budgeted costs for the supporting structure of the building. The building was redesigned to incorporate the modifications in the project documentation so that the first two above-ground floors have monolithic walls (ceramic masonry is used only for partitions), the third and fourth floors utilise ceramic masonry supporting walls and the last floor is made up of a combination of monolithic walls and reinforced load-bearing walls. At the same time,

the ceiling dimensions were changed, with the original ceiling thickness of 220 mm being optimized to 200, 190 and 180 mm. The cost of reworking the project was set at 0.83% of the budget costs for the load-bearing structure. The modifications met the investor's condition that the area occupied by the rooms must not be reduced by more than 5% of the total floor area.

The actual prices for which the work was performed were used for the recalculation. Five subcontractors who participated in the selection process were involved in the construction of the structure.

- Subcontractor 1: Delivery and installation of concrete reinforcement
- Subcontractor 2: Setting up and removal of formwork, laying of concrete, installation of prefabricated elements, crane
- Subcontractor 3: Supplier of concrete mix
- Subcontractor 4: Masonry construction
- Subcontractor 5: Supplier of wall building material

In order to ensure the lowest possible price, the work was divided between several contractors, but this means more responsibility for the general contractor, who has to coordinate all stakeholders and deal with the increased risk of an unexpected rise in the total cost of the work.

4. Optimization of the load-bearing structures of the building

After adjusting the statics calculations and producing the project documentation, the savings were calculated to be 7.4% of the budget costs for the load-bearing structure of the building. There was a reduction in the amount of concrete reinforcement, concrete mixture and formwork. On the other hand, the volume of ceramic masonry increased.

5. The largest savings were made via the following adjustments:

- **Replacement of monolithic walls with masonry** - after calculating the price per 1m² of the load-bearing walls for both materials, the price of load-bearing walls from ceramic masonry was found to be 50% lower than that for monolithic reinforced concrete walls (the calculation considered the price of ceramic masonry, mortar and the installation of fittings; in the case of the monolithic walls the calculation included the price of concrete reinforcement and the concrete itself, including installation and double-sided formwork). The same plasters were applied to both wall surfaces.
Total savings were 2.21% for the whole building.
- **Replacement of prefabricated elevator shafts with monolithic shafts** - Calculations showed that the price of monolithic shafts is 30% lower compared to prefabricated shafts.
Total savings were 0.74% for the whole building.
- **Recalculation of ceiling structures, reduction of slab thickness and concrete reinforcement** - The thickness of the ceiling slabs was changed from the original 220mm to 200, 190, 180 and 160mm, depending on their placement within the load-bearing structure. The amount of concrete reinforcement was reduced from 142 kg/m³ to 101 kg/m³.
This adjustment meant savings of 5.15%.
- **Savings on the thermal insulation system** - By adjusting the ratio of the monolithic perimeter walls to the ceramic masonry used for the perimeter, the amount and thickness of the needed insulation was also altered, resulting in a reduction in thickness from 170 to 120 mm for an area of 750 m². The savings amounted to 0.4% of the budget costs for the load-bearing structure of the building. A small saving was also achieved via a reduction in the workload for adhesive application to mineral wool: the same insulation thickness is used for each floor, so it is not necessary to glue mineral wool batts of different thicknesses together as in the case of a combined system (monolithic wall with ceramic brickwork).
The abovementioned savings in % are always related to the budget costs for the load-bearing structure of the building.

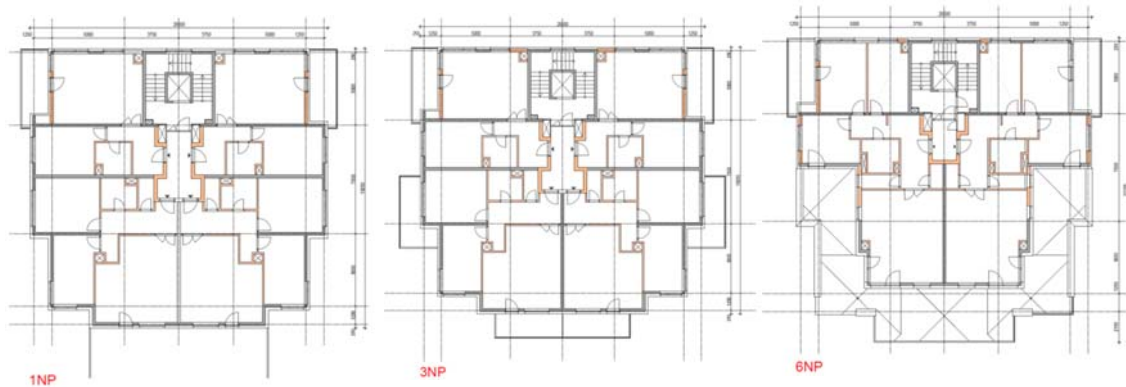


Figure 2. Floor plans of the original design solution - Building 1- 1st, 3rd and 6th storey

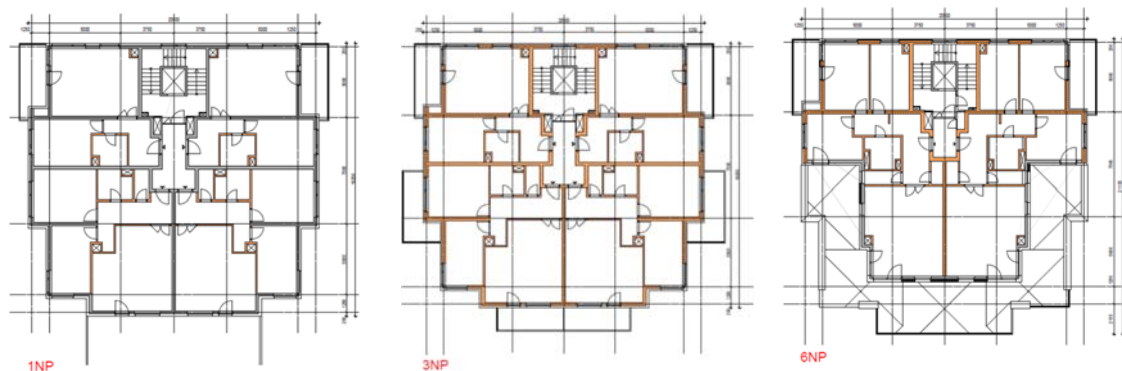


Figure 3. Floor plans of the optimized design solution - Building 1- 1st, 3rd and 6th storey

Table 1. Cost calculation for the construction part of the work based on the real situation

Replacement of monolithic walls with brickwork			
Brick walls, 250mm thk AKU SYM	1	m ²	50%
Fittings, POROTHERM 25 AKU SYM	10.7	pcs	
Wall construction, incl. mortar	1	m ²	
Monolithic walls, 200 mm thick			100%
Concrete for walls above the foundation - reinforced concrete, type C 25/30 XC1	0.2	m ³	
Steel reinforcement for walls above the foundation - steel type 10 505	28.5	kg	
Formwork for walls above the foundation, double-sided, installation, removal	2	m ²	
<i>Total replaced</i>			<i>Savings 2.21%</i>
Replacement of prefabricated elevator shafts with monolithic shafts			
Monolithic elevator shafts			70%
Concrete for walls above the foundation - reinforced concrete, type C 25/30 XC1	2.9	m ³	
Steel reinforcement for walls above the foundation – steel type 10 505	332.5	kg	
Formwork for walls above the foundation, double-sided, installation, removal	38.6	m ²	
Prefabricated elevator shafts	1	kpl	100%
Prefabricated shafts	2.89	m ³	
Construction	2.89	m ³	
<i>19 elevator shafts in total</i>			<i>Savings 0.74%</i>

LOAD-BEARING STRUCTURE OF THE BUILDING COST CALCULATION		PROJECT DOCUMENTATION		REAL STATUS	
Residential complex, Prague		Supplier selection		Optimization	
or d.	Description	UM	Acreage	UM	Acreage
0027: Foundations		16.1%		16.1%	
1.	Concrete base from plain concrete, thickness 100 mm - type C 12/15	m ³	227.0	1.28%	m ³ 227.0 1.28%
2.	Strip foundations and baseplates from reinforced concrete - type C 30/37	m ³	899.5	6.05%	m ³ 899.5 6.05%
3.	Reinforcement of strip foundations and baseplates - steel type 10 505	kg	135 590.0	8.51%	kg 135 590.0 8.51%
4.	Installation and removal of formwork	m ²	220.0	0.26%	m ² 220.0 0.26%
0031: Walls		28.30%		24.55%	
5.	Concrete for walls above the foundation - reinforced concrete, type C 25/30, C 30/37	m ³	1 115.4	6.70%	m ³ 881.2 5.33%
6.	Reinforcement for walls above the foundation – steel type 10 505	kg	131 240.0	8.24%	kg 125 391.3 7.87%
7.	Installation and removal of formwork – double-sided	m ²	10 868.9	13.36%	m ² 9 234.4 11.35%
0041: Ceilings and ceiling structures		38.09%		32.94%	
8.	Concrete for plate ceiling and beam ceiling, reinforced (without reinforcement) - type C 25/30, C 30/37	m ³	1 787.3	11.36%	m ³ 1 731.8 11.20%
9.	Reinforcement for ceilings – steel type 10 505	kg	257 754.0	17.03%	kg 173 881.1 11.77%
10.	Shear reinforcement elements, acoustic spines	kpl	0.0	0.00%	kpl 1.0 0.64%
11.	Installation and removal of formwork for ceilings, without supporting structure	m ²	7 792.3	9.70%	m ² 7 509.2 9.34%
0042: Prefabricated structures		9.74%		7.29%	
12.	Balconies	kpl	1.0	5.14%	ks 1.0 5.14%
13.	Elevator shafts	kpl	1.0	2.45%	ks Incl.
14.	Staircases, inc. acoustic elements	kpl	1.0	2.15%	kpl 1.0 2.15%
0031: Walls		4.30%		7.55%	
15.	Load-bearing masonry - indoor and peripheral	m ²	1 602.9	4.30%	m ² 2 815.0 7.55%
Other items		11.28%		11.28%	
16.	Other - sealing sheet metals, acoustic elements	kpl	1.0	2.13%	kpl 1.0 2.13%
17.	Cranes. Secondary budget costs	kpl	1.0	9.16%	kpl 1.0 9.16%
18.	Processing of project optimization (documentation, overheads)				kpl 1.0 0.82%
Thermal insulation system		0.00%		-0.40%	
19.	Savings via changing the thickness of the insulation	m ²	750.0	0.00%	m ² -0.40%
TOTAL PRICE		107.8%		99.32%	
SAVINGS		8.50%			

RECAPITULATION

Concrete	m3	4 029.2	m ³	3 739.5
Reinforcement	kg	524 584.0	kg	434 862.4
Formwork	m ²	18 881.2	m ²	16 963.6
Masonry	m ²	1 602.9	m ²	2 815.0

Note: The percentage values stated above are related to the budgetary costs for the building's load-bearing structure.

6. Workflow after optimization

During the optimization process, work continued on the execution of the underground structure and the basement. This work went slower than planned in the original timetable. With regard to the deadlines for the gradual issuance of the revised design documentation for the construction part of the project, the overall shift in the implementation deadline was almost three months. The construction of the building was thus completed in January 2015, meaning that the assumption that the building would be completed by winter was not met. Due to the weather conditions at that time, roofing work did not begin until February. The roofs and terraces were completed in May 2015. Work on the thermal insulation system was also launched in February and the construction period was extended until June, the originally planned completion date for the building. At the same time, the deadline for realization of all related professions was shifted. It would have been possible to reduce all the delays through the adjustment of the time schedule for the installation of technical building equipment, building completion and finishing works, but in reality this plan was beyond the work capacity of the contracted subcontracting companies and the coordinating capabilities of the site manager, and therefore it was not possible to meet the planned deadline. In fact, construction was completed two months later than was planned and stated in the works contract.

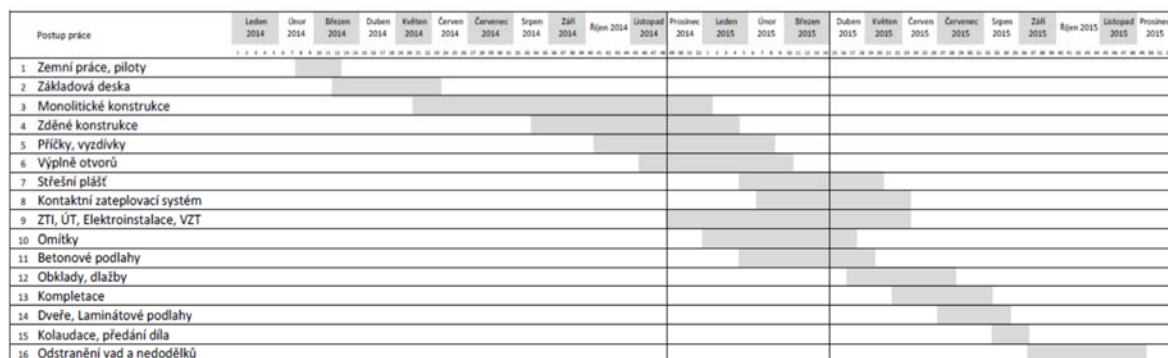


Figure 4. Schedule showing the actual course of construction work

7. Unpredicted extra costs**Penalties for not meeting the deadline**

The valid works contract sets a contractual penalty of 0.05% of the work price for each calendar day of delay. When this sanction is applied to the budget cost of the structure of the building, the penalty is 0.168% per day. As the construction was completed two months later than originally planned, the penalty would have been 10.3%, which exceeds the savings gained. Thanks to the investor's willingness, the two-month delay was approved and no penalty levied. It should be borne in mind that otherwise, any savings resulting from optimization would have been absorbed by the penalties for non-compliance with the deadline.

Overhead costs

The cost of site equipment and wage costs are another burden on the construction budget. Every day of construction delay means an increase in overhead costs. For the mentioned building, monthly overhead costs were 1.93%. The delay of two months increased the cost of construction by 3.852%.

Table 2. Calculation of monthly overhead costs

<i>Site facilities</i>		<i>0.276%</i>
Rental of land for SF, building cells	1 kpl	0.130%
Electricity, water	1 month	0.032%
Rental of tools	1 month	0.016%
Guards	1 month	0.098%
<i>Labour costs</i>		<i>1.650%</i>
Technicians	3 persons	0.588%
Workers' wages	5 persons	0.817%
Travel expenses, accommodation	8 persons	0.245%
Monthly Overhead Costs		1.926%

Payments for energy

When completing the structural work and filling structural openings, the heating of the building was begun. According to the original schedule the building should have already been insulated with mineral wool when winter arrived and the roofs should have been completed. Leakage of heat from a non-insulated building is higher than from an insulated structure, so if the original work plan had been followed, the cost of heating would have been lower, let's say by 40%. Taking into account the actual total price for heating, the savings would have been 0.17%.

The shifting of the completion date and the final handover of the work in the winter months meant the finished building needed to be heated at the cost of the contractor. The handover of common areas and signing over of utilities meters to the prospective user only took place in November. There was an increase of 0.20% in the cost of heating and DHW. This amount is not high in comparison with the total cost of construction, but it is also not negligible.

Heating costs cannot be accurately planned in advance, but based on experience and the circumstances of the given construction work, this amount can be anticipated and minimized via an appropriate approach.

Note: Due to the fact that the delay in building completion was due to the optimization of the load-bearing structure of the building, these costs are percentually related to the costs of the load-bearing structure, [3].

8. Complaints

It is also necessary to take into account the fact that the performed optimization can result in unexpected consequences that only arise during the usage of the building. In the case of this project, these might include higher creep affecting the building than expected, and the cracking of plaster. The problem would arise within the warranty period, meaning the general contractor is contractually and financially bound to deal with the claims, but must count on the financial reserve for such works. The above optimization did not interfere with the underground structure and waterproofing of the building: if unsuitable changes occurred in these parts of the building, the negative consequences would cause more fundamental problems and significantly increase the cost of dealing with claims. In this case, however, it is necessary to distinguish between issues arising due to the poor design of optimization measures and problems resulting from poor implementation and working practices.

9. Conclusion

The realization of a complete structure depends on many factors, of which only some of them can be influenced by maintaining the prescribed quality of the work. It is never possible to know with

certainty what complications might occur during construction, but it is possible to take a large proportion of them into account, to consider them during construction and to at least partly prevent them via suitable solutions and planning.

As part of the optimization of the project discussed in this contribution, savings were calculated and achieved by adjusting the structural design solution. This change, and the delays incurred due to its solution and preparation had an impact on the completion date of the complete work, which resulted in a further increase in costs for the general contractor, and the customer also had the right to claim compensation for non-fulfilment of the deadline.

Table 3. Evaluation of real savings

<i>Estimated savings</i>		<i>Difference</i>	
Estimated savings - construction part	1 kpl		8.50%
<i>Unexpected extra costs, including penalties</i>			14.06%
Penalties for non-compliance with deadline	60 day		9.91%
Overheads cost	2 month	1.93%	3.86%
Increase in building heating costs	1 kpl		0.16%
Heating and DHW costs before the building was handed over	1 kpl		0.13%
<i>Unforeseen additional costs (when no sanction is imposed)</i>			4.15%
Overheads cost	2 month	1.93%	3.86%
Increasing in building heating costs	1 kpl		0.16%
Heating and DHW costs before the building was handed over	1 kpl		0.13%

The aforementioned process ensured an improvement in the financial performance of the construction project, but taking into account all the circumstances, the financial benefit was not the same as initially envisaged. When unpredicted extra costs were counted, the total resulting savings amounted to 4.35%. In an extreme case, if penalties for non-compliance had been applied, the described optimization would have been a major problem that added 5.56% to the financial loss on this project. It is therefore preferable to address optimization and savings in advance (at the project preparation stage) rather than during the construction process itself, as in the latter case the savings achieved can be exceeded by consequent extra construction costs due in particular to the extension of the construction period and the resulting time shift. Due to the mild winter, the costs associated with winter precautions did not increase further in this case, but in future such eventualities need to be taken into account during the planning stage.

Acknowledgment

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