SOUNDING THE POTENTIAL OF LEAN CONSTRUCTION: A CASE STUDY

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Abstract

The paper gives an overview on the results of a case study, where the progress of a fast track office building project was monitored. Two main issues are considered: What were the time and cost consequences of the speeding up methods utilized? What would have been the potential of further speeding up?

Introduction

In this case study, a fast track construction project was monitored by a researcher who first collected all relevant documents of the project. Secondly, he observed and documented ongoing tasks during both design and construction: information flows between actors, tasks dependencies, duration of tasks and problems that occurred. Thirdly, information gathered was completed and checked by interviewing designers and construction parties.

The results of the collection of empirical data were composed to a construction process model (Tanhuanpää & Lahdenperä 1996), which consists of over 1000 design and building tasks, about 850 task dependencies and 450 information flows. The process model is divided into six overlapping phases: briefing and programming, global design, detail design, preparation of construction, procurements and construction.

The information collected has been analyzed from different perspectives: What were the time and cost consequences of speeding methods utilized? Which factors slowed down the project? How much waste was there? What would have been the potential of further speeding up (and making the project leaner), and how could it have been realized?

In this paper, the project is considered against two hypotheses. The first hypothesis is related to fast tracking. The core of fast tracking is in overlapping of design and construction. It has been argued that fast tracking costs more (Kwakye 1991) because the accelerated production rate is above the optimum level of production (the level at which the marginal productivity becomes disproportionately expensive). Fazio et al. (1988) found that the typical trouble areas caused by fast tracking are design-related, and can be grouped into: delaying call for tenders, extending the tender periods, affecting the contractors's ability to plan and execute his work efficiently, and additional work through change orders. Thus, it is investigated whether adverse impacts can be discerned from the utilization of various fast tracking methods.

The second hypothesis is, at first sight, somewhat contradictory in comparison to the first. Here the hypothesis is that Rapid Construction (outcome of a continuous drive for reducing the construction time) can be used as a driver for cost reduction (Koskela & al. 1995). Here, the focus is more on site time, and the point of view is that of a contractor. It is commonly agreed that the elimination of non value-adding time components (waste) in the processes in question is the primary rationale for time reduction. Thus, it is investigated whether such further potential for time reduction can be found.

The Project

The office building in question was realized in a design-build project, where the briefing phase was started already in 1991 but interrupted due to recession, and re-started in December 1994. The design of that 7.100 m^2 and 25.700 m^3 office building, comprising five floors, was started in the beginning of January 1995 and the construction at the end of the same month. The building was finished by the middle of November 1995. It was handed over monthly, floor by floor, starting from the fourth floor at the end of July.

The design time of the building was 9 months, which is quite a standard design time (8 - 12 months) for this kind of buildings. The construction time was 10 months, which, according to statistical analysis, is approximately 25 per cent shorter than the average construction time, 14 months, for a building of that size and construction method (prefabricated concrete frame and facades). The whole project, from the beginning of design, was thus realized in 11 months.

Many players in the construction project had already worked together in the same area having some feeling about the expected quality level and mode of action. The tenant of the building was a growing multi-national company having a clear company vision and recent experience in specifying their office concept. Still, the growth of the organization made the definition of requirements more complicated.

Figure 1. The completed fast track office building project.

Fast Tracking - Methods, Impact and Consequences

Speeding methods utilized

The principal speeding up method was overlapping of design and construction. As is evident from Figure 2, construction was started quite soon after technical design had started. However, 27 % of all design man-hours were done already at that time.

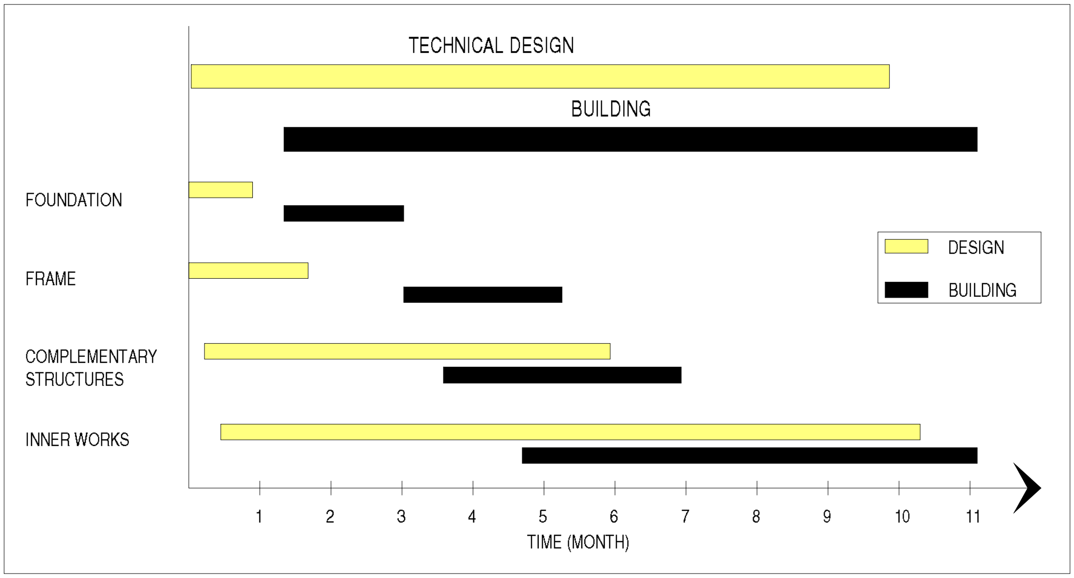

Figure 2. Overlapping of technical design and construction.

In general, this overlapping proceeded without major problems, and the planned schedule could be realized. However, there were cost increases due, indirectly, to this overlapping, to be analyzed below.

In addition to this overlapping, several other speeding up methods were used. Among these, maybe two were paramount: repetition and simplicity.

The building in question was one of a series of buildings, in the same area, sharing many structural solutions and outside appearence, even if the buildings are not identical. This learning effect was amplified by the fact that the design team was the same as in previous sister buildings.

Both the process and product were designed for simplicity, which contributed to rapid execution.

An overview on the speeding up methods and their time and cost impacts is given in Table 1. The time and cost impacts are qualitatively estimated on basis of monitoring data.

It can be said that fast tracking, and especially overlapping, as such did not cause notable delays or major additional costs. However, in various activities, bottlenecks were encountered, and their mitigation was made more difficult.

Bottlenecks

Very few external factors, like material or manpower availability, turned out to be problematic in this project. This is probably due to the deep recession in Finland, having resulted in over-supply of all construction resources. However, the project was slowed down by a number of bottlenecks in different activities (Table 2). By a bottleneck, we refer to deficient capacity, skill or motivation in relation to the task at hand.

The primary factor slowing down the project was client (tenant) decision making. It was delayed both regarding requirement definition and decision making during design. Because of these delays, the capacity in architectural design was exceeded, leading to further delays and problems in design (as analyzed elsewhere (Huovila et al. 1992)). Next, these delays flowed to construction preparation and procurement phases, causing again the amount of work to exceed the capacity of the construction management team. After cascading through the project, these delays were finally absorbed in construction.

The decision to start inner works before the building was water-tight was unlucky. After heavy rains, the uppermost floors were flooded, with consequent material damage and obstruction of work.

Table 1. Speeding methods and their impacts.

Phase	*Speeding method*	*Time impacts*	*Cost impact*
Design	Use of similar solutions as in the previous buildings in the area	Some reduction of design time	
	Same designers as in previous projects in the area	Some reduction of design time	
	Simplification of the design process: hole drawings were not produced, but holes were bored on site where needed	Some reduction of design time	Some increase of construction costs
Construction	Constructability was improved through simple structural design solutions	Some reduction of construction time	Some reduction of construction costs
	Wide use of subcontracting		Some reduction of construction costs
	In critical situations, the use of rapid, but more expensive construction methods	Some reduction of construction time	Increase of construction costs
Total project	Overlapping of design and construction	Notable reduction of the total project time	Increase of construction costs (indirect impacts)
	Construction work was started at the contractor's risk before the final funding decision	Some reduction of the total project time	
	Stepwise hand-over: each floor was taken into use during the construction of remaining floors.	Some reduction of the average project duration	(Increased design effort needed, but not reflected in costs)

Table 2. Project bottlenecks.

Activity	*Bottlenecks*	*Impacts*
Requirement capture	The client could not present requirements and decisions on due time	Design was delayed due to lacking input; increased amount of redesign, delay of resource acquisitions
Architectural sketch design	A part of preliminary design solutions were postponed due to missing agreement	Design was delayed due to lacking input; increased amount of redesign,
Design management	The order of some design tasks was poor	Design was delayed due to lacking input; increased amount of redesign,
Purchasing	Purchasing was partially delayed and prolonged, mainly due to delays in previous activities	Order were placed late; problems in ordering the right amount; change orders
Control of structural works	The date of getting the building water-tight was delayed	Inner works were started before the building was water-tight; due to rain, various problems
Planning of inner works	The schedule was partially slack; work preparation insufficient	Opportunities for schedule reduction were missed
Control of inner works	Insufficient effort to control the realization of the schedule	Uneven resource utilization

Impacts on construction work

Resource utilization for inner works was planned to be even. However, there was a tendency for work to accumulate to the last weeks before the hand-over of each floor, leading to increase of crowding. This is clearly evident in Figure 3, where a histogram of manpower use, both planned and actual, in inner works on the 3th floor is presented. Also, the actual time-space progress of inner work is instructive in this regard (Figure 4).

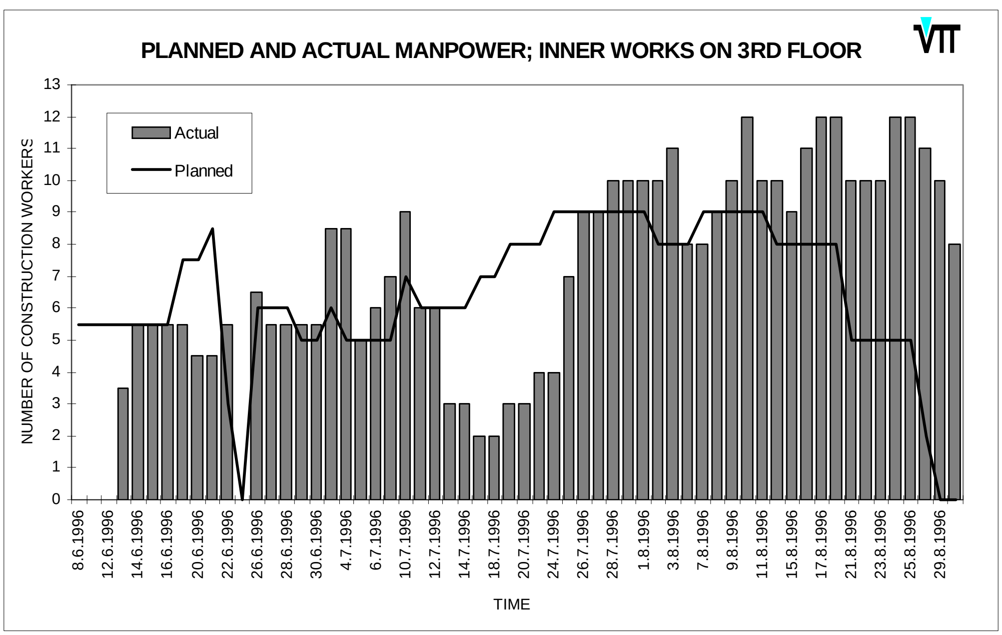

Figure 3. Planned and actual manpower use in inner works; 3rd floor

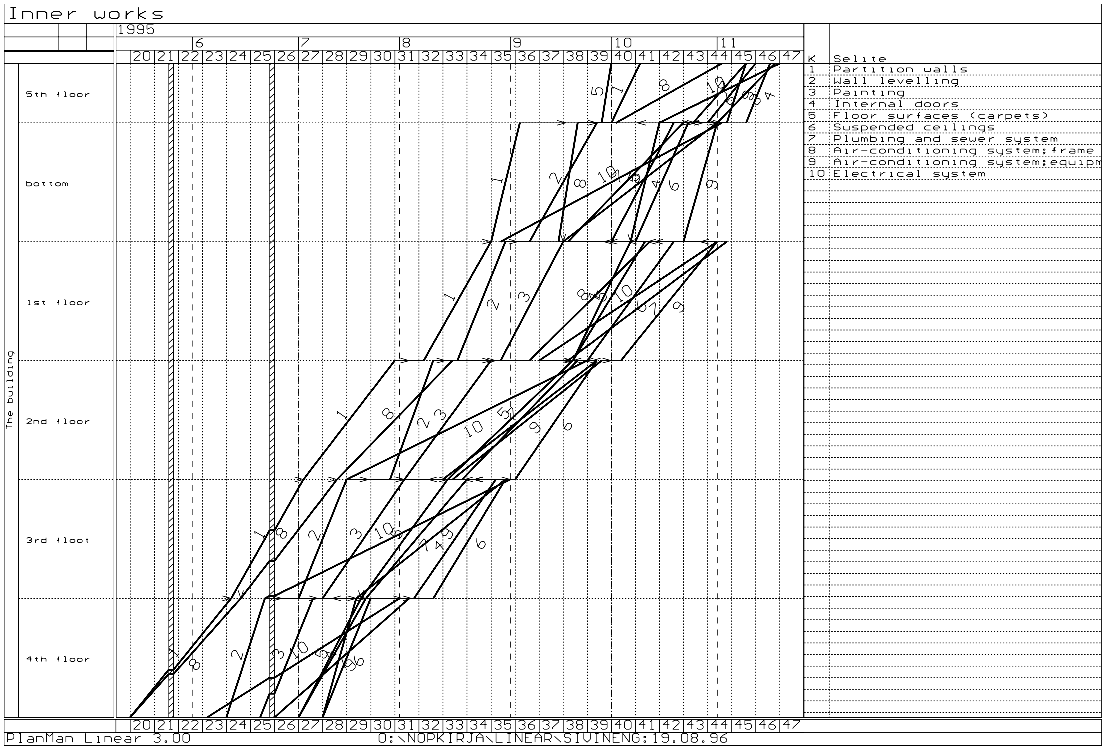

Figure 4. Time-space progress of inner works.

The same tendency of work accumulation towards the hand-over dates is discernible in Figure 5, where the total manpower use on site is depicted. There are clear peaks preceding the due dates of the 4th and 3rd floor. Thus, the construction work is characterized by capacity peaks, where work is done in a rushed manner and in crowded conditions. On the other hand, the relative descent of manpower after the finishing of the 3rd floor indicates certain slackness of schedule.

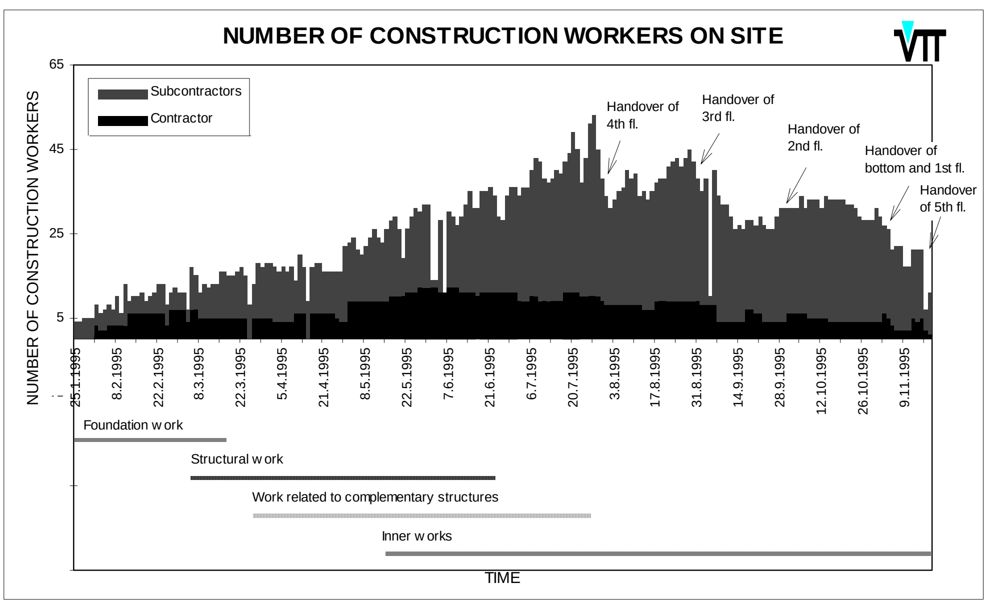

Figure 5. Total manpower use on site. Number of construction workers as entered in the site journal.

The resultant mode of muddling through is evident in data concerning construction activities. In Figure 6, the starting delay and the change of duration of construction tasks are depicted for those activities just before a hand-over date and other activities. It can be seen that the schedule has been caught up during the last activities. The activities before hand-over were, on average, 7 days delayed on start, but only 4 days delayed on completion. In contrary, other activities were on average practically the same time, 7 days, delayed on start and on completion.

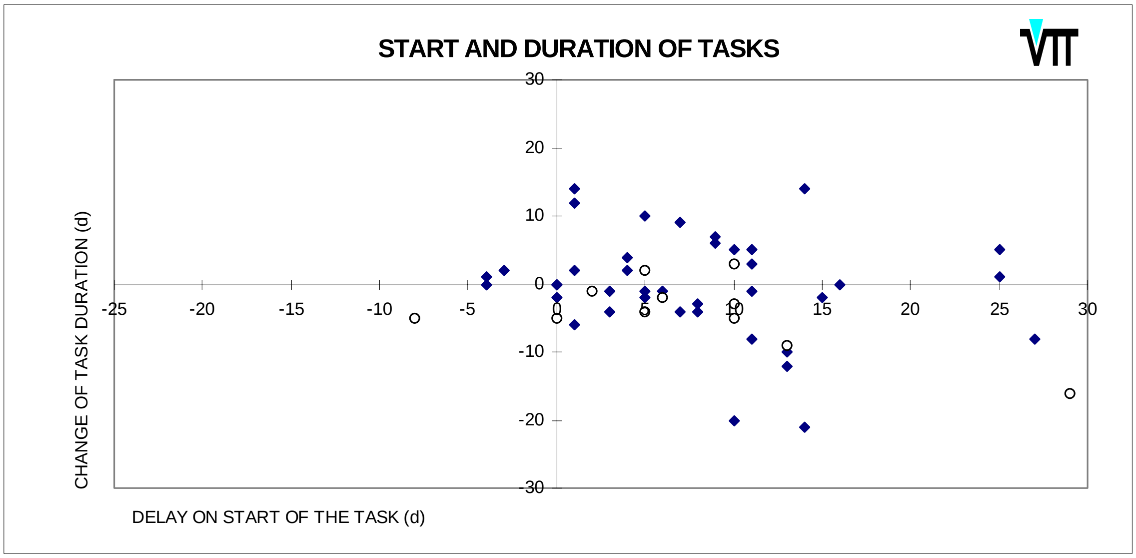

Figure 6. Delay on start vs. change of duration. Tasks next to handover are marked with a circle. Other tasks are marked with a dark square.

How well could the activity durations be forecast? Only 10 % of the activities studied (50) had actually the same duration as planned. The average planned duration was 14 working days. The average extension of duration was 6 days; the average shortening of duration was 5 days. Thus, a rather notable variability seemed to be related to activity durations.

Conclusions

Generally, there were small adverse impacts caused directly by fast tracking in this case. There are several contributing factors for this: resource (both manpower and material) availability is presently (under recession) good; the positive impacts of repetition and learning. However, there are some indirect cost increases, because the mitigation of disturbances (not related to fast tracking as such) is more difficult in a fast tracked schedule. Especially, it seems that the overall variability in the construction process has risen due to fast tracking.

Lean and Speedy - The Further Potential

The above presentation of bottlenecks of the project, firstly, gives us a reason to anticipate that there exists a significant potential in the building process to make it leaner and speedier. The bottlenecks shed light on problems which, according to the general opinion, tend to be typical for the functioning of the building industry in general. What if we were able to get rid of them? In other words:

- what is the effect of fast clarification of customer requirements?
- does it help to get the building water tight earlier and how to do it?
- what if the design proceeds smoothly and the order of all design tasks and information flows can be managed optimally? and,
- is it possible to remove major floats and slackness from the site schedule?

Another relevant question is whether there are any novel means or methods to accelerate the building process that were not utilized in the project in question. One may ask, for instance:

- what is the potential of computer-integrated design?
- how do the system unit procurement and advanced/prefabricated product systems influence the process?
- would the widening of the labour skills towards multi-skillness have any potential? and,
- is the phased occupation in reverse order (in comparison to what happened) possible and what are the pros and cons?

These and many other questions were asked when the study moved to its second phase, now going on. In this phase, improvement ideas were surveyed, the theoretical basis of relevant methods was ascertained and possible pilot cases and experiences studied. Then, the monitored process was redesigned to follow the new ideas. The original activity network and duration data etc. offered a test bench while the realized task- and time-related costs were also used in calculations. Tables 3 and 4 give a few examples of some of the preliminary analyses. The former outlines the starting point, the way of improvement and the application of various accelerating methods in the case project. Table 4 concretizes the corresponding benefits that could be available.

Table 3. A few examples how the building process can be made leaner and speedier. The starting point, way of development and its application in the case project are introduced for each method.

Methods		
Problem	Development idea	Calculation
Minimization of interruptions		
An interruption refers to any deviation from a planned or assumed chain of events that requires spending additional time or money. Major interruptions, ones lasting over an hour, have been found to make up more than 10% of working time in some studies. A large number of interruptions causes not only delays in actual work but also makes it practical	The goal is to minimize the number of interruptions in building construction through continuous improvement of the process. The means include total quality management, teamwork, employee participation, system unit-based organization, more effective job planning, etc.	The study monitored closely the installation of partition walls where additional working times, in excess of one hour, accounted for 6.6% of total work duration. In the calculation a corresponding share of interruptions was eliminated from all work phases on the site. The calculation did not allow for the fact that elimination of interruptions would make it

to maintain a relatively long interval between subsequent tasks. Nevertheless, interruptions in one type of work often indirectly also affect other types of work.		possible to further speed up the project by cutting float. The presumable increase in productivity and decrease in under-one-hour additional working times are also excluded from the calculation.
Reverse order in internal works and stepwise handover		
In Finland, where buildings are generally relatively low, the so-called reverse order is normally followed in internal works, i.e. works are implemented from top to bottom. The procedure is based on following benefits: making the shell give protection from weather, even use of labour, sufficient floats, protection of finished spaces from damage and the "flowing down" of tools and materials. The actual construction time, however, tends to be quite long especially since the typical building is taken into use only after it is completely finished.	The internal works phase is also implemented bottom-to-top according to the timetable allowed by the frame and other preceding works. Sufficient weather protection for the initial internal works is accomplished generally by completing the work on the frame of the floor above first and by providing extra insulation where necessary. Floors are taken into use immediately on their completion. The timing is possible since building services (e.g. heating required for drying and, subsequently, for use) are installed from the bottom up.	Work on site was implemented from the topmost full floor down and the 5th floor was left for last (order: 4th to ground, 5th). The calculations assumed reverse order of implementation as concerns floors 2 to 4, while the order for the rest was maintained (2nd to 4th, 1st, ground, 5th). Thus, the calculation did not take into account all potential for speeding up works. It is also noteworthy that the advantages of stepwise handover had already actually been made use of contrary to normal practice.
Enchanced production planning and constructibility		
The project's production planning strives to compare different productional solutions and to select the most advantageous one. In practice, there is seldom enough time to make sufficiently profound comparisons and planning which results in additional costs, problems and delays in implementation.	Further investment in production planning will ensure identification of the critical points of production, successful comparison and selection of production techniques as well as minimization of risks of implementation. As far as the project is concerned, the idea is to monitor the implementation of the steel frame of the fifth floor, built on site, and its filling with light aggregate. The filling, again, is dependent on the preceding installation of drains in the floor.	In the assumed implementation the frame was made of precast concrete which allowed closing the roof quicker and reduced the costs of protection against fire. The lifting bucket used for light aggregate was replaced by a pump that conveyed the material through window openings and allowed starting work on the frame earlier. Besides speeding up the process, the measures also eliminated the delays and additional costs to 4th floor internal works from water damages.

Great care has been taken in making improvements as realistic as possible, and the supposed advantages are just part of that which could be set strictly on theoretical premises in many cases. The practical implementation of new methods is not easy, of course. Still, the impacts are so significant that even a partial success would mean a great improvement to the present practice.

Another relevant question is: what is the joint effect of these and some other methods studied? Some of the methods need each other to be successful. On the other hand, there are many methods, the impact of which is not dependent on the use of any other methods. We are currently striving to clarify the overall potential.

However, considering the fact that the project studied has been faster than a normal building project, a conclusion can be drawn: that there is a major further potential for speeding up the building process and making it significantly leaner.

Table 4. The time and cost savings of some methods of acceleration when simulated with empirical data from an office building project in Finland.

Methods	Time win[1] [working days]	**Cost savings and incomes [FIM]** [2]			
		Time costs [3]	Direct costs [4]	Earlier incomes [5]	Total [6]
Minimization of interruptions	16	170 000	210 000	130 000	510 000
Reverse order in internal works and stepwise handover	15 [7] (22)	160 000	0	190 000	350 000
Enchanced production planning and constructibility	2 [8] (18)	20 000	120 000	20 000	160 000

[1] This figure describes the shortening of the overall construction period; some methods presuppose some acceleration of design, which, according to research, can be gained by other means quite easily.

[2] The abbreviation refers to Finnish mark; one FIM is equal to £ 0.14 and $ 0.22 approximately.

[3] This accounts for the saving in use of site facilities and equipment, management and supervision etc.

[4] This is a sum of changes in material, equipment and labour-related costs.

[5] The figure summaries the net rent income from the period between accelerated and actual completion.

[6] The figure summaries the other cost columns per method (time and direct costs and earlier incomes).

[7] The first three floors to handover were even 22 working days ahead the actual schedule.

[8] Acceleration is 18 days if the risk (of starting inner works before the shell was water-tight) is accepted as was done on site; by not accepting that risk the saving is 2 days at minimun.

Concluding Remarks

Beyond the work described above, the consideration of a third hypothesis is presently underway. It is related to the discussion about Lean Construction. It has been claimed (Koskela 1992) that “in conventional construction, only tasks are managed, and flows are neglected; as a consequence, construction is characterized by a high share of non value-adding activities”. Can this claim be justified by empirical data and observations?

As a preliminary conclusion, it has been found that generally, physical flows have not been managed, but rather contracts and tasks. The related mechanisms which lead to growing of the share of non value-adding activities are being investigated. Let us only mention one interesting detail. For an outside observer, it is striking to what extent the additional costs due to disturbances, caused by other players, are absorbed by subcontractors and suppliers, and thus do not become visible as construction costs. In the present construction culture, only in the case where the quantities (square meters, etc.) of work are changed, is it fair to present a claim. There is an implicit understanding that disturbances are a part of construction: we tolerate those caused by others, and others tolerate those caused by us. However, from the point of view of lean construction, it is a question of concealed waste - and of a major improvement opportunity.

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