TOWARDS LEAN DESIGN MANAGEMENT

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Abstract
The paper forwards the following hypotheses, which are new or previously little treated, in regard to design management: (1) There is an optimal sequence of design tasks. (2) Internal and external uncertainties tend to push the design process away from the optimal sequence. (3) Out-of-sequence design process leads to low productivity, prolonged duration and decreased value of the design solution. (4) It is possible and worthwhile to enforce (through measurements and managerial control) the realization of the optimal or near optimal sequence. These hypotheses are theoretically grounded and empirically justified through results from case studies and experimentations. Associated methods, like the Design Structure Matrix and the Last Planner, are presented.

Keywords: design management; design structure matrix; short term planning; concurrent engineering.

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INTRODUCTION

It is not an exaggeration to say that the management of design and engineering is one of the most neglected areas in construction projects. Findings from research unanimously indicate that planning and control are substituted by chaos and improvizing in design.

The issue was noted already over 30 years ago in the Tavistock report on communication in construction (Higgin and Jessop 1965):

> *Sufficient thought and time does not seem to be given to ensuring, either as a design team brief or during the designing process, that all who must contribute understand the common objective similarly and fully. There is seldom a full awareness of all the steps necessary to realise an optimum overall outcome without loss of time, and the means of ensuring coordination is often not clear.*

Recent research suggests that nothing has changed. Coles (1990) found that the most significant causes of design problems are poor briefing and communication, inadequacies in the technical knowledge of designers and a lack of confidence in preplanning for design work. Common consequences included slow approvals from clients, late appointments of consultants and inadequate time to complete design documents carefully. In his study on technical design of buildings, Sverlinger (1996) found that the most frequent causes for severe deviations during design were deficient planning and/or resource allocation, deficient or missing input information, and changes. In his study of construction defects, Josephson (1996) found that when measured by cost, design-caused defects are the biggest category. From design caused defects, those originating from lack of coordination between disciplines are the largest category.

To some extent, the situation is understandable. The design effort is complex, with numerous interdependencies, singularly uncertain, with erratic decision making by lay clients and authorities, and often carried out in time pressure. The easiest thing is to let the designers figure out among themselves, in which order the design tasks have to be executed.

However, this situation cannot be viewed as satisfactory. A chaotic design process is not the one where superior functional properties are systematically provided for the client and where constructible design solutions and clear, error-free documents, for their part, ensure a smooth construction phase. Clearly, in order to improve construction in general, the design process has to be better controlled.

OPTIMAL SEQUENCE OF DESIGN TASKS

The Design Structure Matrix, developed originally by Steward (1981), is a method suitable for representing information flows in design. In this matrix, design tasks are first organized in their intended chronological order as matrix rows and columns. If there is a mark over the diagonal of the matrix, it indicates, that a task gives input to an earlier task. This may be due to poor ordering of tasks, or it reflects an iteration (circuit) in the logic of the design process. By means of certain algorithms (called partitioning algorithms), the tasks in the matrix can be reorganized so that only marks belonging to genuine circuits, called blocks (of coupled tasks), remain above the diagonal. This is the optimal order of tasks.

This reorganized matrix provides a starting point for scheduling: the tasks in a block have to be carried out simultaneously, sequential tasks (a mark just below diagonal) in sequence and parallel tasks (no marks linking them) in arbitrary order in reference to each others (Figure 1).

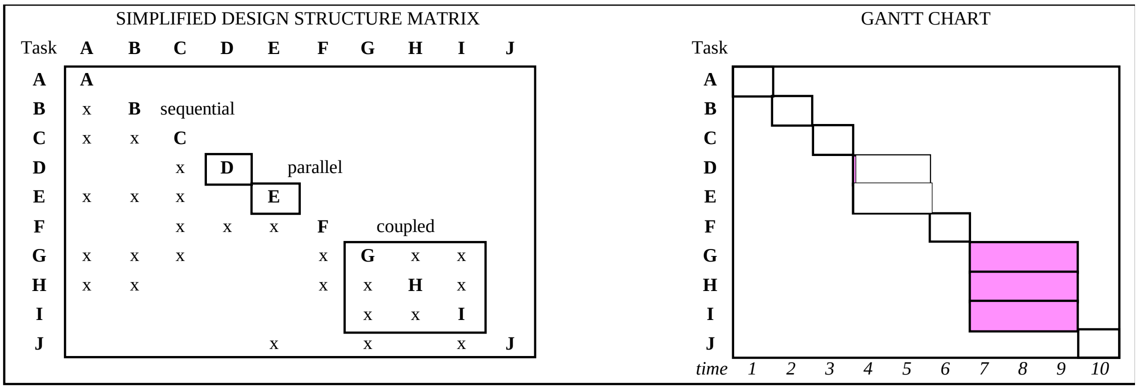

Figure 1 Definition of sequential, parallel and coupled (interdependent) tasks in a Design Structure Matrix.

To what extent, in construction practice, can this optimal order of tasks be known?

The DSM method has recently been investigated in construction (Huovila et al. 1995, Austin et al. 1996). While the initial results are promising, this method is still in the research phase. Only after sufficient testing and launching of commercial software can this systematic tool for finding the optimal order be implemented in practice.

However, the principle of optimizing the sequence can be - and actually is - approached also informally. If the building (or other facility) type is familiar, the designers will have a good feel about the optimal sequence of tasks. In design meetings, designers actively present their input information needs regarding other designers, and the order of making design decisions is thus agreed on.

Often, especially in the early phases of a design project, there is an inherent restriction on determining the optimal order of tasks. This is because the optimal order may be dependent on a design decision to be made: for example, *in situ* construction requires another order than prefabrication. On the other hand, what is important is that the optimal (or near optimal) order of short term (next 2-4 weeks) tasks is known, and this should be possible both through a DSM analysis and also through pooled experience in the design group.

OUT-OF-SEQUENCE DESIGN PROCESS LEADS TO LOW PERFORMANCE

In practice there are several factors tending to push the design process away from this optimal track. Consequently, designers have to postpone their tasks or to cope without complete input information. These issues are analysed as case studies and experiments.

One major issue is that unfortunately building design cannot be scheduled solely on the basis of the internal logic of design. Rather, there are three other parties, the needs of which influence the order of design tasks: construction (order of site tasks), prefabrication (lead time of prefabrication) and controlling authorities (documents needed for authority approvals).

Beyond this,the following factors have been observed as problematic:

- blocks of coupled tasks; obviously, the iteration needed has to be started with incomplete information
- lacking or delayed input from the client (requirements, decisions)
- changes in design objectives or criteria
- unbalanced design resources (especially in a block of coupled tasks, some discipline may be a bottleneck)
- late engagement of a design party
- earlier decisions or intentions not being taken into account in a later task.

A case study (the case described in Koskela et al. 1996) revealed that there are several solutions used for causing the design to progress in spite of lacking input. However, almost every solution brings forth additional costs or an added risk of these. These solutions and their implications are exemplified in Table 1.

Table 1 Solutions used for making the design to progress in spite of lacking input.

Solution	**Implications**	**Examples from case study**
Assumptions are made and checked later.	Leads to redoing if assumptions have to be corrected after checking. On the other hand, checking is easily forgotten or there is no time for it, and a discrepancy between different designs might emerge.	Lack of checking typical especially in HVAC design. Several instances of discrepancies found on site, leading to interruption of work and rushed redesign.
Design input is actively sought in design meetings and per telephone.	Tends to make design work of other designers fragmented, preventing concentration.	Generally used especially at the beginning of the design process
Design iteration is eliminated through an alternative construction method. [This is an instance of a more general strategy for managing uncertainty; i.e. deferral (cf Laufer)]	Usually more expensive.	The holes for HVAC in structural components were bored on site rather than made during prefabrication.
Interface between design tasks is prearranged.	The solution might turn out to be sub-optimal.	The client and the architect could not agree on the entrance. However, an opening for the entrance was agreed between the architect and the structural engineer, so that structural engineering could proceed further.
Design solution is overdimensioned to absorb all possible future decisions.	Sub-optimal solution.	This is generally used in foundation design, when the final weight of the building is not known.
Design solution is selected based primarily on the consideration of design progress (i.e. it prevents the progress of other tasks as little as possible).	The selected solution might be inferior in other considerations, like functionality and cost.	The client could not make a timely decision on the area and other requirements for the topmost, 5th floor (it was to be smaller than other floors). It was decided to construct that floor from steel, because the final weight would be less significant for the structural dimensioning of the building, and the lead time for steel components would be less than in the case of concrete. However, the solution became more complex, and factually resulted in constructability and delivery problems and associated delays.

Thus, experience shows that even if the optimal order of tasks is more or less well-known, problems emerge due to the high level of associated uncertainty and the half-heartedness of efforts to control the design process. These problems deteriorate the performance in the design phase as well as in the construction phase and eventually decrease the value provided for the customer.

ENFORCING THE OPTIMAL SEQUENCE: LAST PLANNER

The planning system

Aside from the simplest and smallest jobs, design and construction require planning done by different people, at different places within the organization, and at different times during the life of a project. Planning high in the organization tends to focus on global objectives and constraints, governing the entire project. These objectives drive lower level planning processes that specify means for achieving those ends. Ultimately, someone (individual or group) decides what physical, specific work will be done tomorrow. That type of plans has been called "assignments". They are unique because they drive direct work rather than the production of other plans. The person or group that produces assignments is called the "Last Planner" (Ballard and Howell 1994).

Production unit level planning

The term "assignments" stresses the communication of requirements from Last Planner to design squad or construction crew. But these products of planning at the production unit level are also commitments to the rest of the organization. They say what WILL be done, and (hopefully) are the result of a planning process that best matches WILL with SHOULD within the constraints of CAN.

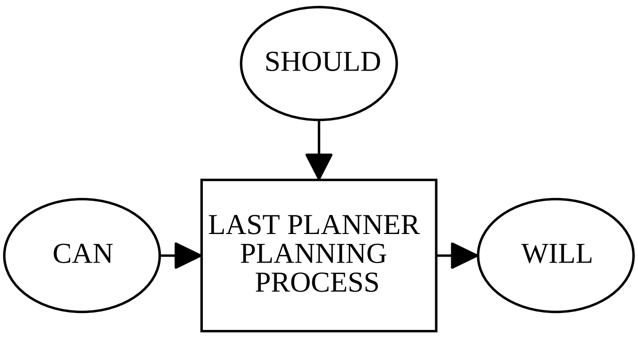

Figure 2 The formation of assignments in the Last Planner planning process.

Unfortunately, Last Planner performance is sometimes evaluated as if there could be no possible difference between SHOULD and CAN. "What will we do next week? Whatever is on the schedule," or “whatever is generating the most heat.” Supervisors consider it their job to keep pressure on subordinates to produce despite obstacles. Granted that it is necessary to overcome obstacles, that does not excuse creating them or leaving them in place. Erratic delivery of resources such as input information and unpredictable completion of prerequisite work invalidates the presumed equation of WILL with SHOULD, and quickly results in the abandonment of planning that directs actual production.

Measuring planning system performance

The key performance dimension of a planning system at the production unit level is its output quality; i.e. the quality of plans produced by the Last Planner. The following are some of the critical quality characteristics of an assignment:

- The right sequence of work is selected.
- The right amount of work is selected.
- The work selected is practical.

The "right sequence" is that sequence consistent with the internal logic of the work itself, project commitments and goals, execution strategies, and constructability. The "right amount" is that amount the planners judge their production units capable of completing after reviewing budget unit rates and examining the specific work to be done. "Practical" means that all prerequisite work is in place and all resources are available.

The quality of a front line supervisor's assignments may be reviewed by a superior prior to issue, but such in-process inspection does not routinely produce measurement data, even when corrections are necessary. Planning system performance is more easily measured indirectly, through the results of plan execution.

Percent Plan Complete (PPC) is the number of planned activities completed divided by the total number of planned activities, expressed as a percentage. PPC becomes the standard against which control is exercised at the production unit level, being derivative from an extremely complex set of directives: project schedules, execution strategies, budget unit rates, etc. Given quality plans, higher PPC corresponds to doing more of the right work with given resources, i.e. to higher productivity and progress.

Improving planning system performance

Percent Plan Complete measures the extent to which the front line supervisor's commitment (WILL) was realized. Analysis of nonconformances can then lead back to root causes, so improvement can be made in future performance. Measuring performance at the Last Planner level does not mean you only make changes at that level. Root causes of poor plan quality or failure to execute planned work may be found at any organizational level, process or function. PPC analysis can become a powerful focal point for breakthrough initiatives.

The first thing needed is identification of reasons why planned work was not done, preferably by front line supervisors or the engineers or craftsmen directly responsible for plan execution. Reasons could include:

- Faulty directives or information provided to the Last Planner; e.g. the information system incorrectly indicated that information was available or that prerequisite work was complete.
- Failure in Last Planner planning; e.g. too much work was planned.
- Failure in coordination of shared resources; e.g. lack of a computer or plotter.
- Change in priority; e.g. workers reassigned temporarily to a "hot" task.
- Design error or vendor error discovered in the attempt to carry out a planned activity.

This provides the initial data needed for analysis and improvement of PPC, and consequently for improving project performance.

Evolution of the Last Planner method

This new production planning and management method has been developed since 1992 (Ballard and Howell 1997). It has been successfully used in a series of projects ranging from oil refineries to commercial building construction. Hitherto it has been used primarily in site construction, rather than in design and engineering.

EXPERIMENTING WITH THE LAST PLANNER IN DESIGN

The applicability of the Last Planner method to design management was tested on a construction project in Finland.

The project

The office building in question is realized in a fast track project, where the building design phase (global design) was started in the middle of September 1996. The detail design of the 7,600 m^2 and 30,500 m^3 building was started in the end of October and construction in the beginning of November 1996. The first section of the building (about half the building area) is to be handed over at the end of July 1997 and the rest of building is to be finished one month later.

The project is based on a fixed price design-build contract with a rather detailed specification of the building. The form of the building has been determined in an architectural competition. The architect, the structural engineer and the designer for prefabricated components work for the construction contractor. The HVAC works are realized as a design-build subcontract for the construction contractor. Accordingly, HVAC designers work for respective subcontractors.

The construction time is tight, at least 25 % shorter than the statistical average. Thus, a good control of the design process is a prerequisite for a successful project realization.

Conventional design management

Since the progress of an earlier roughly similar neighboring project, with partly the same players, was monitored earlier, it is possible to describe the conventional design management process that would probably have been realized in this project without the experimentation.

A drawing due date schedule, and a summary drawing circulation list form the basis of design management. There are design meetings every two weeks or so, where a contractor representative (site manager) acts as the chairman. The contractor may also organize meetings to address specific problems between design disciplines.

Thus, the primary control set is to reach the drawing due dates. Instead the order or timing of individual design tasks is not scheduled, but are left for self-management by the design team. In practice, the design tasks to be executed or input information needed are discussed in the weekly design meetings. However, this procedure is not perfect. There is no effective follow-up of decided action, and only a part of output due is often available. It seems that often parties come unprepared to the meeting. Design decisions are often made in improvized style, and decisions taken are not always remembered in next meetings.

Experimental design management

Clearly, the conventional method does not produce “quality assignments”, as defined above. Thus, it was necessary to intervene into the design management process in several ways.

Firstly, for ensuring a globally right order for design tasks, a detailed design schedule based on a realized design schedule of a corresponding project (Tanhuanpää and Lahdenperä 1996), a DSM analysis and designer interviews was composed. During the progress of design, the schedule was updated (rather than made more detailed) in one-month slices. Secondly, the researcher documented the input information needs, which designers reported in design meetings (an example: Determine the position of the shaft for electrical cables to the ventilation machine room). Thirdly, the tasks for the next period (taken from the schedule) and information needs were discussed and agreed in design meetings, and they were attached as assigned design tasks into minutes, which were sent to all design parties immediately after the meeting. Thus, each party, including the owner and the tenant, received a form presenting his scheduled design (or decision) tasks for the immediate future.

In the next design meeting, the assigned tasks were systematically dealt with and monitored. The assigned task forms were returned by all parties, along with information about the realization of each task, and the cause for non-realization, if applicable.

In contrary to the procedure used in Last Planner applications for site work, the resulting graphs of task realization were not presented in design meetings. This was decided in order not to create an atmosphere of overly tight control.

Results

As evident from Figure 3, PPC rose soon to the level of 70%. However, in the design meeting 9 the tenant presented a wish of changing a corridor bridge to a neighboring building, originally designed for the 3rd floor, to the 4th floor. This also led to some layout changes on related floors. In addition, the layout of the 2nd floor was respecified. For these reasons PPC temporarily decreased, but rose then again to 70 - 80%.

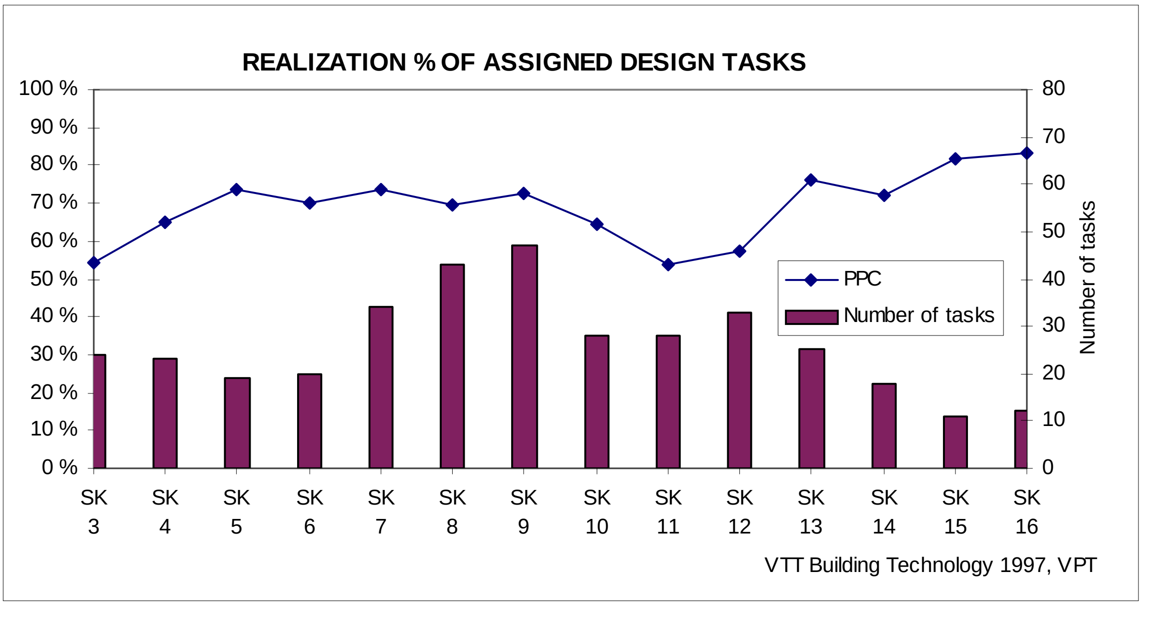

Figure 3 Percent plan complete and corresponding number of tasks in each design meeting (SK). The interval between design meetings 3 - 8 was one week, between 9 - 14 two weeks, between 14 - 15 three weeks and between 15 - 16 four weeks.

The causes for lack of task realization, investigated starting from the design meeting 7, are presented in Figure 4. Roughly half of the causes (lacking input and lacking decision) are related to variability in the overall design process. The other half of causes (had no time due to other tasks, duration of task optimistically estimated) are related to internal planning and management of each design discipline.

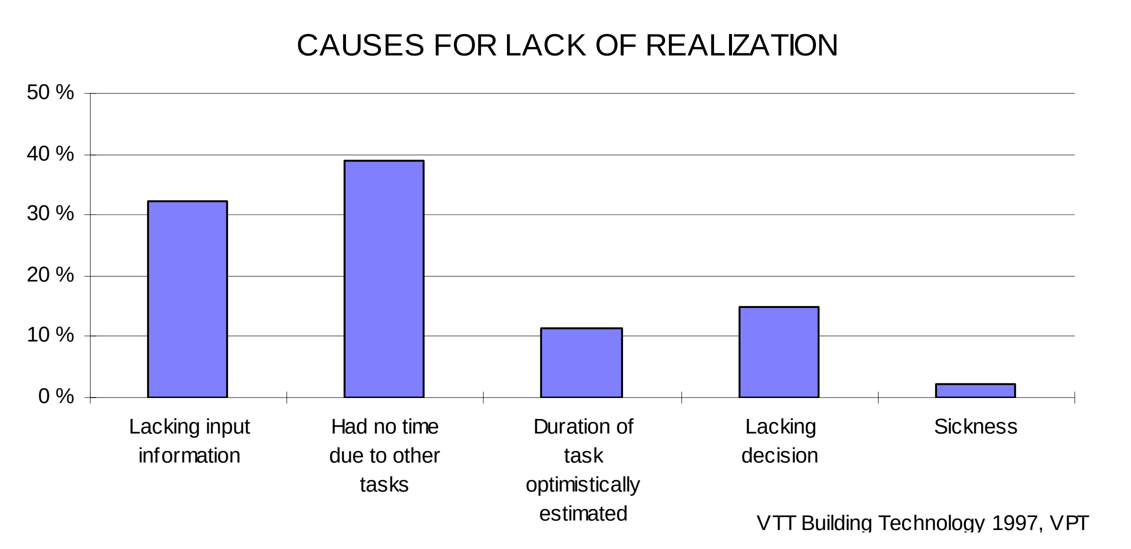

Figure 4 The causes for lack of realization of design tasks.

The evolution of frequency of causes for lack of task realization is shown in Figure 5. The category "Lacking input" has a clear downward trend, whereas the categories "Had no time" and "Lacking decision" remain statistically on their respective stable levels. That the category of "Lacking input" dominated still in the meetings 7 and 9 is apparently due to the elaboration of remaining tasks in a large block of interrelated tasks (the existence and location of the block was known from earlier analyses). Instead, the high frequency of this category in meetings 11 and 12 is indirectly due to tenant initiated changes. In the remaining design meetings the share of "Lacking input" was little, due to the increased degree of completion of design. The mentioned tenant iniated changes are also directly reflected in the high number of "No decision" causes in meeting 10, a clear deviation from the trend regarding this category. The behavior of the category "Had no time" is more erratic, which is understandable because it reflects conditions largely due to factors outside the project.

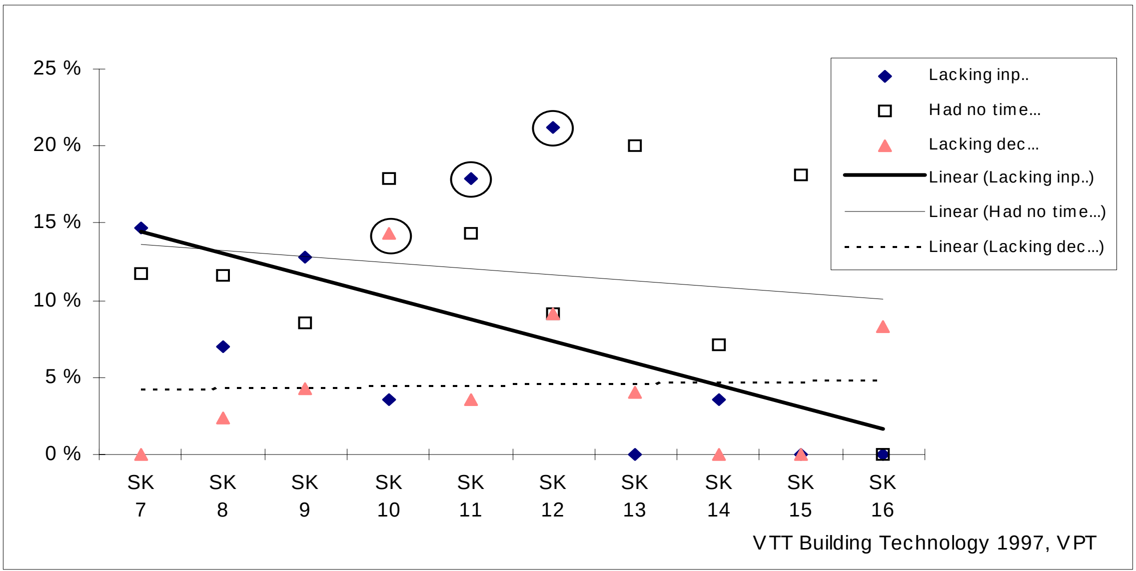

Figure 5 Frequency of the three most important causes for lack of realization of design tasks during the design process and corresponding regression lines. Deviating points have been circled.

In this first experimentation, there was no attempt to act on causes found. However, in view of the analysis above, it seems that the most fruitful cause category to act on would have been “Had no time”. This would have meant focusing on the internal planning and management system of each design discipline.

Evaluation

The design time of the building, except for minor complementary design tasks and redesign, was a little bit over 6 months (as was scheduled), which is about 30% under the standard design time for this kind of building. It is also possible to compare subjectively this project to the earlier monitored project (Tanhuanpää and Lahdenperä 1996), (volume and quality level concerning corresponding the case project), which was built about one and half year before in the same area. In the earlier project, the design phase lasted 9 months, and impacted negatively the construction process (Koskela et al. 1996). In all respects, the experimentation produced a superior design process.

The order of magnitude of extra man hours required by the experimentation was 5 % in comparison to the total design man hours and less than 0,5 % in comparison to the total project man hours. It can be assumed that the benefits widely exceeded the costs of the experimentation.

The views of the participants in the design group were investigated by means of a small questionnaire. The questionnaire was sent to eleven parties, and eight completed it. The results are summarized in Figure 6. It is evident, that the parties involved viewed the experimentation largely positively. All wanted to the method to be used in the next project; all viewed that it is not laborious to use the method.

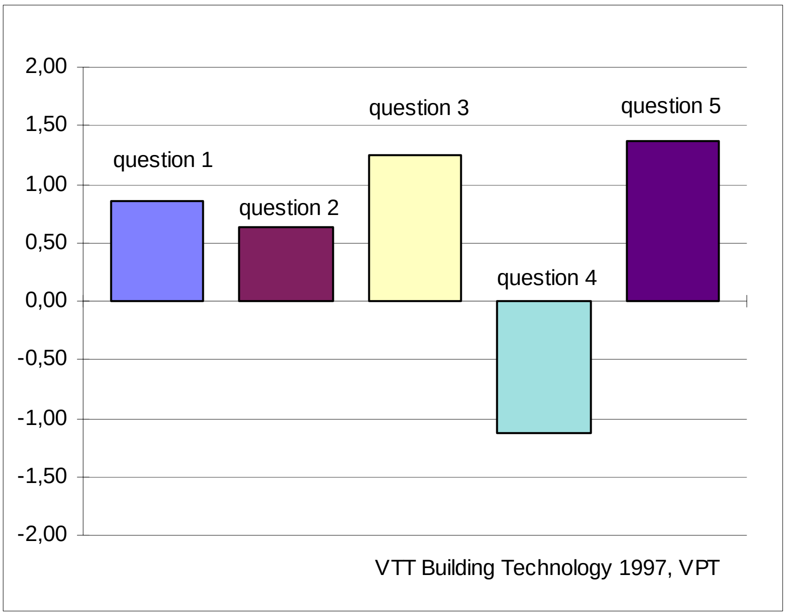

Figure 6 The average replies, on a scale of -2 to 2, to the questions :

1. Was the availability of input data improved?
2. Was the decision making in design process improved?
3. Did the method yield benefits?
4. Was it laborious to work according to the method?
5. Should the method be used in the next project?

The applicability of Last Planner in design management

The experiment gave initial proof that the method of Last Planner can effectively be used in design management, along with other associated methods. The resulting design process was definitively more disciplined in comparison to a process managed in conventional style, even if only a part of the Last Planner features were used (performance feedback and impacting on causes were not used).

There are two major benefits associated with the use of this method in design management. Firstly, the design process is made transparent through both the schedule (and the underlying design structure matrix) and the metrics of PPC. The impact of, say, a design change to the schedule can be better analyzed in advance. The impact of, say, an erratic decision making behavior of the client can be made visible through PPC graphs. It is the lack of transparency that, for its part, has made disruptive decisions and practices possible in design. Secondly, a metrics (PPC, cause category frequencies) for design management is provided, making possible to benchmark, to set targets and to monitor progress across projects. The lack of metrics has up till now effectively hindered improvement of design management.

Further research

The results of this experiment invite further research and testing, both for achieving a firm empirical justification for the method and for refining it.

Replication of the experiment in other projects, similar or dissimilar, would provide information on “normal” levels of PPC in design and about differences due to project type. Comparison with control projects would determine the improvement achieved.

One important extension is to focus on improvement on the fly. By presenting the PPC graphs to the design group, a joint effort to increase the PPC level could be stimulated. What rate of improvement is possible?

Another area for development is the chain from the master schedule to assignments. How can DSM in practice be used as a basis for scheduling? What is the best way of lookahead planning? The principle of deriving the assignments partly from the overall, rather detailed schedule (intersection of SHOULD and CAN) and partly from immediate input needs presented by designers turned out to be feasible in this case. What if the design task is more novel, and it is difficult to make more than a summary schedule?

The cause categories should be more detailed. For example, the cause “had no time due to other tasks” should be divided into two causes, distinguishing between other tasks in this project and tasks in other design projects. Also distinguishing between Changes in Priority and other causes, such as a previous task extending beyond its estimated duration, could be instructive.

In hindsight, the decision to treat the client parties (owner, tenant) in the same way as designers turned out to be a very successful solution. In this way, the client parties were sensitized to the disciplined action required for the sake of smooth progress. But can we generally assume that the client is willing to be involved?

DISCUSSION AND CONCLUSIONS

It is clear that the practice of design management is often deficient. However, these results also show that the conventional prescription of project management is not enough in design context. It is not sufficient to identify the tasks to be executed, to find their interrelationships and, on that basis, to prepare a schedule. Rather, the inherent variability at the task level has to be fought by means of suitable production control methods; otherwise, a great share of tasks are carried out in suboptimal conditions (part data missing), with resultant performance loss along the whole chain of the project.

But for achieving a truly excellent design process, even more is needed. Often there is a trade-off between the schedule goals and the objective of meeting the customer requirements in the best possible manner. Thus, we should avoid one-sided concentration on schedule and task control: sometimes it is quite justified to sacrifice the smooth progress of design for improved customer value. The best solution is to develop and to use systematic methods (like QFD) also for the value generation dimension of design, as argued in more detail in (Koskela and Huovila 1997).

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