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Learning by doing: Public and private search for quick delivery and sustainability in building projects

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Abstract

Quick project delivery makes socio-economic sense as value can be delivered sooner. We investigate two approaches to achieving this; the modular super cube-concept for school buildings and conventional building conducted in series (repetition of design and floor plans between buildings). We study the methods and evaluate the degree of success in quick project delivery, while also looking into sustainability-aspects of the two cases. The identified enablers of speed include clear owner priorities, learning effects and quality assurance at the conceptual level. The enablers of sustainability include clear owner priorities. We then evaluate if there have been a trade-off between the concerns for sustainability and the goal of quick project delivery, identifying cost as the suffering factor.

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Keywords: speed; learning effects; sustainability; trade-offs

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1. Introduction

The aims of profit, cost-efficiency and quality are important drivers in the evolution of any sector, including building and construction [1]. Reductions in construction time for building projects allows property developers higher turnover rate on projects and thus increased profits without increasing the profit margins on the individual project. Reduction of construction time can also be a target for actors in the public sector, in order to provide capacity and facilities for schools and health care to serve the population.

Meanwhile, changing regulations and expectations from stakeholders with regards to environmental impacts and sustainability force whole industries to innovate and approach projects differently with regards to planning and execution [2, 3]. "*Sustainability"* of buildings and projects however remains difficult to pin down and measure. A range of organizations has proposed various approaches formalize the "sustainability" of buildings, including certification (BREEAM, LEED and Green globe). Academics in the field of sustainable construction are working towards the same goal [4-6]. At it's core sustainability is about balance and trade-offs; it is a holistic concept that revolves around local *and* global, short- *and* long-term concerns and consequences within the environmental, economic and social dimensions.

The purpose of this paper is to document the process and findings of two case studies in which construction speed (or quick project delivery) and sustainability have been of the essence. The research questions we have addressed are: (1) what are the *enablers* that contribute to the achievement of quick project delivery and sustainability in the delivery process and in the delivered asset (the building) and (2) are there trade-offs that result from simultaneously pursuing quick project delivery and sustainability in process and product. An enabler is defined by the Cambridge dictionary as "*something or someone that makes it possible for a particular thing to happen or be done*" (2017). A barrier denotes the antonym, "*anything used or acting to (...) block something from happening*". A trade-off is defined as "*a situation in which you balance two opposing situations or qualities*".

Speed and sustainability may appear to be examples of two such "opposing qualities"; one focusing on the short-term delivery, whereas the others main concern is the long term. We have used a mix of methodologies in covering the two cases, including interviews, questionnaire surveys and action research in order to identify the enablers and the trade-offs in the process of achieving quick project delivery and sustainability in the delivery process and the product that have been delivered.

Case study 1 is of a module-based concept for school construction (primary school extensions) of which 8 cubes have been constructed. The principal argument for developing the concept was initially quick delivery of additional capacity to schools that were either becoming to small due to population increases, or to replace outdated temporary barracks dating from the last 40 years. However, after the four first cubes had been delivered, policy changes in the municipality resulted in new requirements with regards to the energy use and insulation meant that the subsequent four cubes were to be delivered according to passive house standard [7]. *Case study 2* is of an apartment complex at Fornebu outside Oslo. Four nearly identical apartment buildings are being constructed at half the time of "normal" projects. Disregarding the short construction time, the building process is conventional building, meaning prefabrication is used for structural elements such as columns, elevator shafts and hollow core floors, whereas the rest of the building is done at the site.

Table 1: overview of cases

	Case 1: Super Cubes	**Case 2: K2 apartment complex**
Project size	Seven projects each around 2000 sq.m.	Four apartment blocks 15 100 sq.m.
Building method	Prefab steel modules	Conventional hybrid construction (prefab/place built)
Type of contract	Design build alliance	Engineering, procurement and construction contract

Learning effects due to repetition within and from one project to the next pose a great opportunity for improving project performance with regards to both speed and sustainability. Experience can help both decision-makers and

workers when faced with trade-offs, and ensure that mistakes and bad decisions are not repeated when faced with identical or similar situations again. The two cases offer different forms of repetition and types of learning; the K2 apartment complex offers identical floor plans within each apartment block, and the apartment block itself is nearly copied four times over. The school construction projects are spread over a longer period of time and the case is investigated from the owner and user perspectives rather than the contractors'.

Our benchmarks for measuring quick project delivery stem from a comparative study of construction time performed as part of the Norwegian SpeedUp-project. In the project we gathered data from more than 150 construction and building projects executed over the course of the last ten years. A large portion of the projects are large public buildings (in the range between 2 000-10 000 m^2). The duration of the construction phase of projects is in most cases measureable as start and end points are clear. Variables include size (square meters), type of project (residential, business/office, schools etc), contractor, sub-contractors and project owner. The duration of the planning phases provided more of a challenge to measure, as projects move through different planning and approval cycles between initiations and approved financing depending on the project owner (e.g. private, municipal or national projects). The starting point in the eyes of one actor could be developing of the concept or idea, while for another actor the starting point is marked by starting the engineering phase or by the reception of a letter of initiation.

2. Methodology

The relations between theory and research can be described as *deductive* (theory guides research) or *inductive* (theory follows from research). Induction means drawing universally valid conclusions about a whole population from a number of observations. Deduction means deriving logically valid conclusions from given premises – to derive knowledge of individual phenomena from universal laws [8, 9]. We have alternated between inductive and deductive approaches in an iterative process, seeking to better understand theory and practice. Tjora [10] classifies this as an *abductive* research approach. To ensure sufficient validity and reliability of the findings we have applied triangulation and a combination of qualitative and quantitative data, as described by Yin [11].

Three literature reviews have laid the groundwork for the deductive approach. Project management is a trans-disciplinary field with relevant publications in journals not primarily focused on project management alongside the dedicated project management journals. According to Cook, Mulrow [12] the origin of structured literature review (SLR) is in medical and health care fields. As compared to many traditional and less systematic approaches for carrying out literature reviews, SLR is generally considered to be superior in terms of transparency as other researchers can more easily verify the findings of the study by replicating the research setup. During the last two decades organization and management scholars have begun to adopt SLR in their research designs as well [13]. While working on the two case studies we have executed four literature reviews; on sustainability in project management ([14]), on sustainability strategies ([15]), time management [16] and on industrialization ([17]).

Table 2: Overview of research methods

Methodology	Case 1: Super Cubes	Case 2: K2 apartment complex
Literature review(s)	X	X
Interviews	X	X
Questionnaire survey	X	
Action research		X

The inductive approach has been most evident in the interviews and the action research performed on the case studies. The case study of municipal school building was centred on the Super Cube modular school building concept. It has been performed as an ex-ante evaluation after the completion of seven projects. However, in the process, we have also evaluated four place built school extension projects and the construction of two complete schools. It can be argued that although we are denoting the school building as a single case study, it is one with several embedded projects. Interviews have been performed with actors within both the "buyer" (4 interviews) and

"supplier" (4 interviews) entities of Oslo municipality, as well as with teachers (5 individual and 1 group interview) and facility management staff (4 interviews) who use the school buildings. In addition, usability aspects of the school buildings have been covered by use of a questionnaire distributed to the teachers whose "home" classroom is situated in one of the Super Cube buildings. The K2 apartment complex opened up and invited active participation by the researchers in the form of action research [18]. The researchers attended their weekly status and planning sessions for a period of six months. The researchers also contributed to the organization of focus groups for planning, and participated in on-site coordination activities performed by the various sub-contractors foremen. The researchers followed the construction over the course of several months, and interacted with the project by helping develop and perform quality assurance of the production plans and in the organization of reflection/learning seminars.

3. Theoretical background

3.1. The rationale for pursuing quick project delivery

Quick project delivery gives the project owner and the users of the delivered asset access to the project's output sooner than would otherwise be the case. It can thus begin to provide value and return on investment, so quick delivery makes economic sense. There is generally a close relationship between project's duration and its total costs. Large projects cost more than small ones and complex projects cost more than simple projects. Kerzner [19] states that as even the smallest change in a project can affect the overall, developing a process for handling trade-off is preferable to "hard and fast" rules. For some, but not all types of costs, there are trade-offs between cost and delivery time (when quality or performance is kept constant). The relationship, or trade-off, between cost and time is generally in the form of a u-shaped curve where the cost increases at both ends – i.e. in the one end with extreme time compression, and with time extensions on the other. When significantly compressing the duration of projects, i.e. speeding up, the resulting extra cost is referred to as "crash cost". Crash cost is in most cases used when the compression is such that the actions taken incur disproportional additions to project cost. The crash cost consists of factors such as extra administration, additional resources (manpower and equipment) and rework. The crash cost is most likely to be represented in cases where projects must recover lost time to get "back on track". In the other extreme, slow progress and subsequently, long project durations may increase cost due to time-dependent costs such as rig and operating expenses. However, cost is just one factor in deciding the appropriate or ideal duration of a project.

Johansen, Landmark [20] used the term "time elasticity" for evaluating projects appropriate duration and pointed out that the different project roles, such as contractor, project management team, project owner and the society in general, have different opinions on what the optimum delivery time for projects are.

There is a range of factors that influence whether a project *can* be delivered to the preferred point in time. One is the quality of the engineering team's deliverables that are very influential for the planning of the building process. Other factors include the amount of workers that are appointed to the project, the quality and productivity of the work force, the opportunity to work around the clock (one, two or three shifts), factors dealing with the work site (logistics, work and material flow) various bottlenecks (lifting capacity of cranes, numbers of gates), choice of building or construction method (use of offsite/prefabrication or place built) and dedicated time for testing and control activities. The financial incentives and penalties in the contracts wield large influence over how the different actors respond to questions of speeding up project delivery. In the absence of financial incentives for delivering early combined with significant penalties for delays, it should come as no surprise that most project managers focus on delivering to the agrees time.

3.2. The rationale for pursuing sustainability in project delivery

The World Commission on Environment and Development definition of sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [21] serves as the a conceptual starting point for the definition of sustainability and the inherent conflict of interest between current development and long-term precaution. The 1987 report has been central in the

interpretation of sustainability as consisting of three dimensions: the ecological, the economical and the social dimensions. The case for business and corporations to include a similar multi-dimensional approach was made by Elkington [22]. In the "triple bottom line"-concept corporations are urged to adapt to a world in which business goals are inseparable from the societies and environments in which they operate. The three dimensions of the concept were dubbed the "Triple-P's" for *people*, *planet* and *profit*. Several authors has since developed the concept further [23] , and made the business case for the sustainable corporation [24, 25].

The attention to sustainability and environmental concerns has since increased, further establishing sustainability as one of the mega trends that shape current transformations and developments in many industries. National authorities wield large influence over building and construction as clients and regulators and can use that power in order to meet national obligations. The UN Sustainable development goals consist of 17 goals (and some 169 targets) of which the member states are obliged to pursue [26], and provide the grounds for tighter regulations and building codes both for buildings performance and the materials used. Many developers and contractors seem to have picked up on the development. The adaption to and mitigation from the effects of climate change is probably the most influential of these for the project management profession [27]. The Paris accord provides binding obligations in order to retain global average temperature increase at below 2 degrees [28]. The construction sector has long been identified as a culprit with regards to sustainability, and especially environmental impacts. It uses three billion tons of raw material, making it the number one global consumer of such [29] and generates 20 % of the solid waste stream globally [30]. On-going urbanization and population increases will additionally emphasize the key role of actors in the building and construction sector in handling these global challenges.

4. Results and findings

4.1. Quick project delivery

The Super cubes have been successful in reducing the lead-time from project initiation to handover. By performing a quality assurance of costs for the *concept* rather than individual projects, planning time is reduced considerably. It is however, not primarily the time actually spent planning that is reduced, but rather time spent for quality assurance and awaiting approval for financing (two sessions per year) that is responsible for the reduction in duration. Using standardized units and performing groundwork and production of the modules in parallel have contributed to the reduction of the duration of the construction phase. The average project duration has been 22 months compared with 52 months for place built school extensions. Although the reduced lead-time was the initial rationale for introducing the cubes, it is the build-quality that has made them popular in the Municipal Undertaking for Educational Building and Property. Technical installations have been functioning better from handover than the case is for comparable place-built projects, and the teachers enjoy the spacious and bright classrooms.

Table 3: Project duration of Super Cube projects compared to place built school extension projects

	Duration from initiation to construction	Duration of construction phase	Project duration
Average Super cubes	12	10	22
Average school extensions	31	21	52

The construction of the K2 apartment complex began in august 2016. In the course of the next year, four apartment blocs consisting of a total of 150 apartments have been constructed. During the initial six months of the project, production suffered from inadequate detailed planning. The workers on site were forced to await clarifications and drawings from the architects and the consulting engineers. Difficult ground conditions lead to further delays that remained present throughout the construction period.

Shortened construction time was possible due to two main factors; series production and learning effects. The production was similarly divided in two; the initial groundwork and installation of prefab (concrete hollowcore

floors and elevator shafts, steel frame and bearings) had priority access to the on-site crane and were to proceed independently of other activities at the site. The prefab components were delivered from Poland and Romania by truck. Learning effects in the workforce materialized as process optimization and reduced need for re-work for the place built parts of the apartment complex. During the construction, the project management team with the main contractor invited representatives from all the sub-contractors to dedicated "learning seminars" were the participants put forward their experiences of "what went well" and "what went badly".

The primary learning effects however, materialized in the day-to-day work. The Project management team was able to optimize the production processes, based on experience with the actual production from the first apartment bloc, in order to better organize the flow of activities in the construction of the subsequent buildings.

4.2. Prioritized sustainability aspects

Environmental concerns play a large part in the municipality's tendering documents and contracts. The municipality is certified according to ISO14001 and both the Agency for Education and the Municipal Undertaking of Education and School Building are obliged to take environmental concerns and life cycle costs into account in the tendering process. Still, price remains the most important criteria for choosing contractors. Normally 70-80 percent of the decision hinges on price; total costs, unit costs, labour costs and the cost of potential options. The remaining 20-30 % hinges on capacity, ability to deliver and competence of involved parties.

"Sustainability" as such was not stated as a target quality in the development of the super cube concept. However, several factors that contribute to sustainability were part of the rationale for developing the concept; design for lower operation- and life-cycle cost, higher build quality, flexibility and movability and low energy usage. The adaption of the original cubes to passive-house-standard proved to be a lessor challenge than first feared, as the primary design change was 5 cm of extra insulation.

The K2 apartment complex has been promoted to the marked as consisting of environment friendly and energy-efficient housing. The buildings themselves however, merely fulfill local regulations with regards to energy efficiency, insulation and heating. Emissions from the construction phase and transportation of materials have not received any particular attention in planning phases. The social dimension of sustainability has been important, with special attention to working conditions and transparency in the use of sub-suppliers.

Table 4: Identified sustainability aspects

	Public: Super Cube school extension	**Private: K2 apartment complex**
Prioritized sustainability aspects in product	Life-cycle cost, energy-efficiency, working/learning conditions	20-minute city/neighborhood, energy-efficiency
Prioritized sustainability aspects in production/delivery	Transparency, choice of materials and suppliers	Transparency/working conditions, limitations to working hours (due to noise/light for neighbors)

4.3. Enablers and inherent trade-off between quick project delivery and sustainability

The project owner was the primary driver for pursuing quick project delivery and sustainability in both cases. Delivering faster at equal quality will in normally result in a trade-off where cost rise [19]. It was only in the school construction case that there was initial acceptance for higher cost, and the project owner expected that standardization and gradually lower production costs would offset the higher cost of the first extension projects.

The standardization of the project delivery also contributed to the quick delivery by effectively eliminating time-consuming activities in the municipality's quality assurance scheme as the concept was deemed pre-approved after

the two first uses. The flexibility of the super cubes, including movability, had been one of the sustainability-related qualities of the cubes during its development. These were identified as adding too much to the cost of the cubes, and were only present in the first couple of cubes.

The quick delivery of the K2 apartment complex hinged on the contractors ability to exploit the opportunities that accompanied serial building; efficient use of the site and manpower. The workflow was optimized based on experience from actual progress, and the workers from different technical disciplines learned what parts of their job directly influenced other workers' ability to do theirs. According to the foremen, when asked if the requirements that had to be met in order to fulfill the goals of low energy usage contributed to slow the projects progress, the answer was "no". When the project was running late, the contracts limited the subcontractors' ability to engage extra manpower due to transparency rules.

Table 5: Summary of findings

	Public: Super Cube school extension	**Private: K2 apartment complex**
Enablers of quick project delivery	Clear owner priority Pre-approval (QA) of solution	Clear owner priority Serial building Learning effects
Enablers sustainability aspects	Clear owner priority Flexible production	Clear owner priority Serious actors
Identified trade offs	Cost increase	Cost increase

5. Conclusion

We have studied two cases in which quick project delivery and sustainability have been important success criteria. In both cases, it is the project owner who has been the driving force behind both success criteria. In the public case, speed was motivated by acute need for capacity. In the private case, quick delivery was financially motivated.

Quick project delivery is normally regarded as one of the main advantages of prefabrication and modular construction. In our case study of school construction, the development and use of prefabricated modules significantly reduced the project duration compared to on-site building. The case study of the K2 apartment complex illustrated that conventional building with high degree of place building can be delivered even quicker. An important factor in the quick delivery of the K2-project was learning effects. By having the same project management team, and the same group of contributors with the suppliers, learning effects both among the builders on site and the management teams resulted in continuously faster building.

When time and performance are kept constant, deviations in plan will normally lead to a trade-off with costs expected to increase. Both cases ended up at higher construction costs than initially planned for. As a result, the modular school building concept will be revised with emphasis on lowering costs. On the other hand, the team behind the K2 project expect to be able to deliver similar projects at lower costs next time around.

The findings from the two case studies are in line with expectations and prior findings. However, additional case studies balancing the restrictions of time, cost and quality in the long and short term can provide further insight into the trade-offs faced by project owners and the contractors.

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