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Effect of systematic completion on public construction projects

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Abstract:

Purpose:
The purpose of this article is to analyze the effect of a systematic commissioning process on project management performance of construction projects, expressed as cost, time, quality and customer satisfaction. The building commissioner in focus uses the term systematic completion, defining it as a structured process throughout the whole project assuring the fulfillment of functional requirements in the building.

Methodology:
A qualitative single case study was used to analyze the effect of a systematic completion process by one Norwegian building commissioner in the public sector, exemplified with four projects. The analysis was conducted by studying project documents and conducting interviews.

Findings:
Systematic completion has a positive effect on the performance of a construction project, enabling completion on cost, schedule and with fewer defects at handover. Involving facility management assures mutual learning, trained operations personnel, and potentially lower costs of operations due to fewer corrections and optimized systems. Higher efforts and resource use in the early phases of the project and in testing are largely offset by the generated benefits.

Limitations:
The case study is limited to the building commissioner's perspective in four projects. The design team's, the contractor's and the client's perspective is not represented in the study. Only one of the projects is completed, which limits the ability to draw quantitative conclusions.

Originality/value:
Existing studies focus on the technical aspect of systematic completion. The present study provides valuable insights into the effect of systematic completion on project management performance, especially on its implications for the takeover of the building by operations.

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1. Introduction

The completion of a building with all its complex technical functions is the final milestone of the construction phase of a project. But why are so many projects not ready for operations at completion, even though this is agreed upon in the beginning of the construction phase? In many projects, it takes a long time before the owner finally agrees to take over the building from the contractor. In some cases, like the Berlin-Brandenburg airport, substantial construction flaws and technical difficulties led to a repeated postponement of the opening. However, there are also large projects completed on time, within budget and with the desired quality, such as the 14 billion NOK enlargement of Oslo airport completed in 2017. A systematic approach to completion is named as a success factor, focusing on operational readiness throughout the whole project, and working with continuous training of the operations staff (Langlo et al., 2018). Also other large public buildings in Norway, such as the new Munch museum and several school buildings recently finished or under construction use a similar approach to completion.

To assure operational readiness, a thorough commissioning process has been used in the shipbuilding and oil and gas industry for a long time. It was adapted to the Norwegian construction industry under the term "systematic completion". Systematic completion is a managerially driven process integrating the completion aspect into all phases of the project, with the purpose to fulfil all functional requirements in terms of time, cost and quality (Johansen and Hoel, 2016).

From 2018 on, Statsbygg, the Norwegian government's key advisor in construction and property affairs, requires all construction projects to use their procedure for systematic completion. The procedure provides a detailed list of actions with designated responsibility for all phases of the project, including testing. Two design instruction documents complement the procedure: one on systematic completion (Statsbygg, 2018) and one on the systematic collection of documentation for operations (Statsbygg, 2019). The building commissioner's documents build on the Norwegian Standard "Commissioning and testing of technical building installations" (Standard Norge, 2016). The standard outlines the processes for successful commissioning and trial operations of technical building installations, independent of the contract form. The core drivers for this process are to achieve operational readiness at completion, and well-functioning integrated complex technical systems in large projects, where technical installations take a larger share of the total delivery than before.

The effect of systematic completion on construction projects is not well documented yet. This case study looks on its effect on project management performance of public construction projects from a building commissioner's point of view. Project management performance means completing a project within schedule and budget and with the required quality (Cooke-Davies, 2002). Project success, the achievement of the project's business objectives (Pinto and Mantel, 1990) is touched upon in terms of customer satisfaction.

To concretize the research topic, this paper addresses the following research questions (RQ):

RQ1. Which effect does systematic completion have on project management performance of public construction projects?

RQ2. What are the prerequisites to make systematic completion work?

RQ3. What are the learning effects from systematic completion?

The article starts with presenting the theoretical background and the methodology. Findings from the case study are presented and discussed. To conclude, the research questions are answered based on the findings.

2. Analytical framework

2.1. Commissioning

Commissioning originally started in the shipbuilding industry to ensure that ships are ready for service (Mills, 2011a). It was later transferred to buildings to assure that today's buildings with complicated technical systems work properly (ibid.). Mills (2011a) gives the following definition of commissioning:

> *"[B]uilding commissioning brings a holistic perspective to design, construction, and operation that integrates and enhances traditionally separate functions. It does so through a meticulous 'forensic' review of a building's disposition to identify suboptimal situations or malfunctions and the associated opportunities for energy savings." (p.149)*

Commissioning especially takes into account the integrated nature of building systems (Khalilieh, 2014), "preventing system interface complications" (Schneider et al. 2016, p.313). This makes it an important tool for quality assurance and for cost-effectiveness in construction projects (Mills, 2011b). International standards, like the ISO 9000-standards for quality management can also serve as the basis for commissioning interpreted as a project-specific quality verification throughout the whole project (Wayne and Wade, 2002).

Commissioning has both costs and benefits: "Benefits can include energy savings, reductions in other utilities, and lower operations and maintenance costs. Costs include the identification and resolution of deficiencies [...], along with documentation [and] training" (Mills, 2011a, p.152). It can also "avert premature equipment failures", "mitigate indoor air quality problems, increase the competence of in-house staff, and reduce change orders" (Mills, 2011b, p.88). A thorough commissioning process with functional testing of technical systems can avoid leaving the correction of technical defects until operations (Shirkavand et al., 2016), which has been the case because clients tend to wait until operations to point out defects, or because contractors deliberately wait with the correction of remaining errors (Lohne et al., 2019). Kalilieh (2014) adds enhanced security, quicker occupancy with fewer complaints from occupants and lower overall project cost as benefits. Although commissioning is often seen as a confirmation of successful integration of installations (Ellis, 2015), using it as a continuous process with customer and user participation through all project phases, is considered to give the highest benefit (Dvir, 2005, Hopps and Babaian, 2014). "Starting commissioning tasks late in the design or during construction limits your ability to make needed changes easily and cost-effectively." (ibid., p.2). Other prerequisites for successful commissioning are third party control, alignment with the owner's requirements (Hopps and Babaian, 2014) and learning from previous projects (Ágústsson and Jensen, 2012).

2.2. The interface between construction projects and facility management

In the commissioning process, the interface between construction projects and facility management (FM) can pose a challenge. Scarponcini (1996) argues for an integrated approach to FM with a holistic view of life-cycle management. A higher investment in the design and construction phase is needed in order to optimize the costs of operations. "With 85% of the cost of a facility after it is built, it was believed that the additional cost of capturing information needed for maintenance and operation, during the design and construction phases, would be significantly offset by the resulting lower cost of maintaining the facility." (ibid. p.3). A Danish questionnaire survey reveals difficulties in operation due to the legacy from the projects, especially problems with documentation and indoor climate (Rasmussen and Due, 2019). Jensen (2012) found a limited degree of knowledge transfer from operation of existing buildings to new buildings. The involvement of FM both in the early design process and throughout the commissioning process is one mechanism to counter this problem (ibid.; Bjørberg et al., 2017). Also Boge et al. (2018) conclude that including FM already early in the project improves a building's lifetime value creation and results in a high perception of a building's usability by the user. In addition, FM should be part of the quality assurance to follow up that early specifications are met throughout the project (Bjørberg et al., 2017). The transfer of the building to operations benefits from detailed specifications, clear agreements about quality, third party inspection and not accepting late design changes (Schneider et al., 2016). Also Jensen et al. (2019) discard the idea of considering a new building as a 'wrapped gift' to operations, encouraging instead interactive collaboration throughout the whole project to enable reciprocal knowledge transfer. From a value management perspective, there is great potential in changing the view from FM as a controlling instance reducing cost, which is often neglected in course of the construction process, to FM as an active stakeholder contributing to increased value creation in the whole life cycle of the building (Jensen et al., 2013).

2.3.Systematic completion (SC)

To answer the need for a holistic commissioning process of technologically advanced buildings, assuring a smooth transfer of the building to operations, the concept of SC has emerged in Norway in recent years.

"Systematic completion is an assurance that the project fulfils all functional requirements within the set time-, cost- and quality requirements, planned and verified by a structured process which is managerially driven from design and planning to handover." (Johansen and Hoel, 2016, p.9; translation by the author)

Planning should support both the functional requirements and the building's geometry, and work in the project should be done right the first time to achieve a well-functioning final product (ibid., p.9). Various rounds of testing, an interdisciplinary approach, as well as involvement and training of operations personnel assures robust systems and elimination of errors as early as possible (ibid., p.4/14). The resulting V-model is based on a Systems Engineering approach, where the left side represents the creation of systems requirements and the right side the integration of parts and verification against the requirements (Department of Defense, 2001). The V-model has also been adapted in the ISO 15288 standard for systems engineering (ISO, 2015) and is elementary for SC in the represented form.

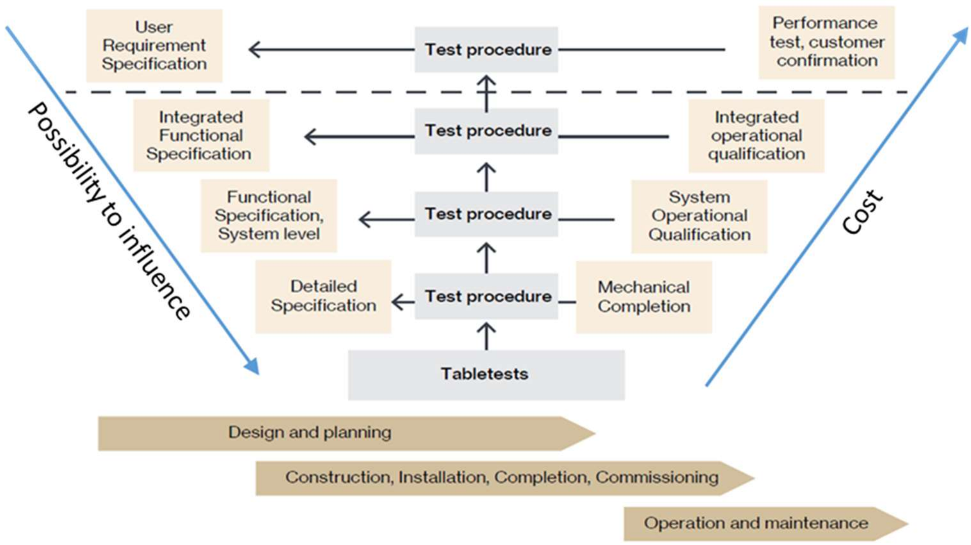

Figure 1 The V-model: Connection between engineering and testing (Holm et al. 2018, p.83; slightly adapted by the author)

The V-model as displayed in Figure 1 shows that the possibility to influence decreases gradually in the project. After construction has started, changes entail gradually increasing costs. Different levels of tests in the model assure early detection of deficiencies and optimization of systems as soon as possible in the process. Table tests after the completion of engineering constitute a theoretical review and verification of each technical system. Next, the installation of separate systems is verified, followed by testing of integrated functions and final testing of the complete system. In all tests, actions (results, errors, rectifications) are transparently documented. Agreement of test acceptance criteria beforehand avoids conflicts in the project and gives higher predictability of the final commission.

To summarize, SC is the full integration of the completion aspect into all phases of the projects – and this distinguishes it from a traditional approach of a more arbitrary 'unsystematic completion' of construction projects. Early functional specifications serve as the basis, activities in the project are planned with completion and operations in mind, and deficiencies are eliminated as early as possible. The process is incorporated formally into the system and thus less dependent on individuals. Sequential testing, including theoretical table tests, and the involvement of personnel from operations, leads to a systematic commissioning process, which goes beyond a "functional testing of the different parts and systems before handover" (Shirkavand et al., 2016, p.5) by an external service provider.

3. Methodology

3.1. Research approach and methodology

A qualitative case study approach with triangulation of document analysis and interviews was used (Neuman, 2006). According to Yin (1981), a case study is a useful tool of empirical inquiry of "a contemporary phenomenon in its real-life context" (p.98). A single-case design is used, studying four projects handled by the same building commissioner, which allows for controlling one variable within the same context (Yin, 1981). A document study of four construction projects was followed by a series of semi-structured interviews (Neuman, 2006) with participants from the project management teams of those projects.

The author of this article is employed by the building commissioner and has access to project documents and interviewees, but has not been directly involved into the projects and has taken a researcher's role in this analysis in order to avoid bias.

3.2. Data collection and data analysis

In a first step, the building commissioner's general documents concerning SC were reviewed. Afterwards, project documents for systematic completion for four construction projects (cf. Table 1) were studied. For project 1 (Faculty of Fine Art, Music and Design of the University of Bergen), the only completed project at the time of the study, also meeting minutes and project finances were part of the analysis. The document study gave an overview of the formal implementation of SC in the projects. To get an insight into how the project organization perceive the impact of the implementation of SC in their projects, eight semi-structured interviews with nine people were conducted after the document study. Through purposeful selection, the author identified several of the interviewees herself based on professional knowledge of the projects. The first interviewees suggested the remaining interviewees. All had practical experience with SC on the commissioner's side within their respective management / technical coordinator roles. Seven interviews were face to face with one person, and one interview was conducted with two people jointly via skype. Most of the interview questions were case-specific, while in a few questions, interviewees could refer to their experience from other projects. As a small quantitative element, all interviewees were asked to rate statements on the effect of SC. All interviews were audiotaped and transcribed for analysis.

Interviews were analyzed in two rounds: A first open coding round placed the data into preliminary analytical categories, which helped to identify any surprising aspects (Neuman, 2006). In addition to three codes explicitly covering the research questions ("effect on project management performance", "prerequisites" and "learning"), the codes "attitude to and description of SC", "test regime", and "interface to operations" were added. In a second round of axial coding with focus on the coded themes, the codes were applied to all transcripts (Neuman, 2006). All coded aspects were summarized in a spreadsheet to get a complete picture.

3.3. The projects

The case study comprises four construction projects conducted by Statsbygg, the Norwegian Directorate of Public Construction and Property Management. Table 1 gives an overview over the projects:

	Project 1	Project 2	Project 3	Project 4
Name	*Faculty of Fine Art, Music and Design of the University of Bergen*	*New Building for Life Sciences of the University of Oslo*	*Western Norway University of Applied Sciences in Bergen*	*New National Museum in Oslo*
Type of building	University building	University building (incl. laboratories)	University building (incl. administration)	Museum
Gross area	14 800 m^2	66 700 m^2	14 300 m^2	54 600 m^2
(Expected) completion	April 2017	2024	April 2020	2020
Cost frame / expected cost	1.114 bill. NOK (price date July 2017)	6.8 bill. NOK (incl. user equipment)	0.5 bill. NOK (price date Dec. 2016)	6 bill. NOK (price date Sept. 2018)
Contract form	Contract management approach (11 contractors and design team)	Partnering approach with consecutive turnkey contracts	Turnkey contract	Architecture competition and contract management (27 contractors and design team)
Approach to SC	Building commissioner initiated SC from engineering phase on, in parallel with developing the Norwegian standard/ guide-book on SC	Building commissioner introduced SC in engineering phase, project team overlap with project 1, collaboration on SC with design team and contractors	SC led by the contractor and embraced by the project organization (from detail engineering)	Building commissioner initiated SC as a new process during construction phase

Table 1 Overview of the case study projects

4. Findings and analysis

4.1. Analysis of project documents

In project 1, SC was used in combination with a LEAN approach. In the engineering phase, SC requirements were included in the call for tender. A list over the technical infrastructure and all systems, as well as a test plan (theoretical table tests – area and system function tests – integrated tests – full-scale and user tests), test procedures and detailed functional specifications complete the foundation for SC. A training plan for FM was established.

Key figures from an internal project database for project 1 show completion of the project on time at a final cost of 99% of the internal cost frame. The absence of a specific cost item on SC makes it difficult to estimate any extra cost, but no change orders directly related to SC were issued. The minutes of the meetings between the project and FM show few guarantee issues after completion. Trial operations started as planned and FM overtook the building much earlier than similar projects. Operations perceived the standard of the technical documentation as higher than in other projects. After the trial period, the building commissioner overtook most of the technical systems from the contractors. Shortly afterwards, operations overtook responsibility of the building, with only two minor issues still handled by the project organization. Operations received 150 000 NOK to cover potential future issues – a low amount compared to other projects of similar size. The project was ahead of possible problems through continuous testing and early involvement of the operations team, resulting in a very low number of flaws in the final product. Transparency and good communication throughout the whole construction and trial operations period also contributed to a smooth transfer to operations.

The project published several brochures with an evaluation and their learning effects from SC. The project team especially stresses the importance of preventive planning with focus on completion already in the engineering phase, involvement of the user and FM, and table tests as a final step of system engineering to reveal unsettled issues with technical systems.

In project 2, the building commissioner, the design team and the contractor collaborate on SC. A claim by the engineering team for 2 000 extra working hours due to SC gives an indication of extra costs in the early phases. For the contractors, SC should not lead to unexpected extra costs, as it is integrated into the contracts. At the time of the study, project 2 is in the detail-engineering phase. Several of the project team members have previously worked with project 1. SC has been one of the main processes of the project already from early stages on, reflected by a SC strategy and a dedicated project manager for SC. The strategy covers the interface between technical systems and the geometry of the building, as well as the different stages of tests. The test regime is the same as for project 1, with the addition of stability- and performance tests as a supplement between full-scale test and user tests. The strategy for SC lists documents to be established in the course of the detail-engineering phase, such as an action plan for SC, a list of all systems and a plan and procedures for testing.

Project 3 has not established any project-specific documents for SC, but uses general documents and instructions issued by the building commissioner. The turnkey contractor has established own documents for SC.

In project 4, a procedure for SC was established early in the construction phase. Later, plans for takeover and handover as well as for training of facility management was specified, and the building commissioner's general plan for transfer of the building to operations was adapted to the project. Even if a procedure and plan for testing was written, those plans proved to be insufficient. In summary, there was a good formal structure for SC in the project, but it was difficult to follow in practice, partly because important structures and documents were established too late to be included into the contracts with the contractors.

4.2. Interview findings

Knowledge on and description of systematic completion

All interviewees know the concept of SC, the guidebook and the Norwegian standard for SC (Standard Norge, 2016). Four interviewees have experience from one project with SC, three have participated in two projects with SC and one has worked with completion of construction projects in a systematic way since 2004, although he did not call it SC previously. One person has long experience from commissioning in the oil and gas industry. All but two interviewees also have experience from projects without SC. They agree on SC being "not entirely new and revolutionary", "no rocket science" or "hocus-pocus". One interviewee expresses it like this: "For many years, I have wished to work in this way in order to complete buildings on time, but we lacked the tools for it and the acceptance in the market."

The following statements illustrate the interviewees' attitude interviewees towards SC:

> *"My slogan for systematic completion is to start with thinking about the end."*
>
> *"The systematic reasoning behind the principles is to put in effort early to profit from it at a later stage in the project."*
>
> *"Systematic completion is about more than working systematically. It is about the integration of all and everything and about a broad interdisciplinary understanding of all functions."*

In project 1 (Faculty of Fine Art, Music and Design of the University of Bergen), a pilot for SC, the acceptance was high, apart from initial scepticism of some contractors. In project 2 (Life Sciences, University of Oslo), SC has been an integral part of the project from the early phases on, and discussions have changed from getting acceptance for SC to optimizing solutions. In project 3 (Western Norway University of Applied Sciences), SC was implemented early and is described as well working with the turnkey contractor as one of the main drivers. For project 4 (The New National Museum), SC was introduced at a later stage and the interviewees had to “lobby” for SC among the engineering consultants and the contractors.

Test regime

All projects have a sequential test regime in place, perceived as beneficial by the interviewees. However, no table tests were performed in project 4, as SC started later in the project. Interviewees ascribe the highest saving potential to table tests, although some contractors were dissatisfied with the time-consuming exercise. Also component and system tests have revealed deficiencies, e.g. concerning the ventilation system in project 1. In project 4, more defects were discovered in integrated tests. Interviewees express the importance of integrating testing in schedules and allowing enough time for preparation to ensure readiness for testing.

The interface to operations

All interviewees stress the importance of a continuous involvement of facility management in the process of SC. They estimate that positive effects offset the associated costs:

- Resources from operations contribute to the project with their experience to optimize solutions from a facility management perspective, which also has an educating side effect on the engineers.
- Training of facility managers is integrated in the project, leading to a competent facility manager feeling ownership of the building.
- The takeover of the building by operations goes smoothly, because there are fewer defects and FM is familiar with the systems.

The effect of SC on cost, time, quality and customer satisfaction

“There is a lot of money to save if we can avoid sitting with a completed building with many deficiencies for three years without being able to transfer the responsibility of the building to operations”. This reflects one interviewee’s experience from a previous project where 7.5 million NOK were used for correction of flaws after completion. Two other interviewees recall instances where they have been engaged at the final stage of a project to “tidy up”, a time- and cost-extensive process. Interviewees express the effect of SC on project costs as follows: “The whole process with systematic completion has [...] reduced unnecessary costs in a very simple and continuous way.” and: “You avoid using money, which you originally have not planned to spend, but which you normally end up using nevertheless.” Several interviewees expect a positive effect on operations cost due to fewer defects, trained facility management and optimized systems with complete documentation; potentially also through lower energy consumption. All interviewees agree that SC is important for reducing uncertainty concerning the final product, as the process assures a building where systems function well from day one. A statement from project 1 illustrates this: “I think that we would not have been able to complete the building within cost, time and quality without these processes.” Interviewees also name a positive effect on customer satisfaction in project 1: A well-functioning building and competent facility management contribute to high customer satisfaction.

Prerequisites to succeed with systematic completion

One of the prerequisites to make SC work is to integrate it fully as a management task into the project. General documents by the building commissioner, including design instruction documents, are mentioned as a key to success. Enthusiasts and a good project culture across organizational boundaries contribute to the successful implementation of SC. One of the interviewees stresses the importance of team members with previous experience of SC. “You need to have been part of the process once to see the point of it. It is not enough just do read theory and documents.”

SC requires more coordination and planning in the earlier phases of the project. All interviewees advocate starting early, with good functional descriptions, corresponding test procedures and system lists. This enables designing the building for completion, setting up the time plan accordingly, and including requirements for SC in contractual agreements.

There is ambiguity towards the importance of a tool for completion. It is perceived as beneficial, that the building commissioner has a tool for SC under development, but interviewees are sceptical towards testing a tool under development in a large project like project 4. Some of the interviewees mean that full understanding of the SC process is necessary before introducing a tool.

Learning effect

The interviewees agree on a high degree of continuous learning, especially in their first project with SC. This is especially encouraged by many competent people in the project organization and by a low level of conflict, providing an arena for dialogue and collaboration.

Learning for future projects includes:

- Start the SC process early in order to integrate it into design and the project schedule.
- Establishing thorough test procedures based on good functional descriptions, as well as (standardized) system lists early in the project, combined with interdisciplinary tagging of components.
- Optimization of tests and resource utilization for preparation of test procedures, limiting length of and participation in tests.
- The importance of functions and interdisciplinary collaboration.

These lessons have been partly integrated into the building commissioner's general procedures on SC.

Testing statements on SC

At the end of the interview, interviewees were asked to which extent they agree with eight statements on the anticipation of positive effects through SC compared with traditional projects without SC. The statements are taken from the guidebook on SC (Johansen and Hoel, 2016).

Claims: Through systematic completion, projects can achieve the following:	**No. of answers for each score**					**Average score**
	1	**2**	**3**	**4**	**5**	
	Highly negative effect	Negative effect	No effect/ neutral	Positive effect	Highly positive effect	
Early detection of errors avoiding costly rectifications.					8	**5**
Better involvement and training of operations personnel.				1	7	**4.875**
Good final documentation.				1	7	**4.875**
Better quality of building and installations.				2	6	**4.75**
More accurate lifecycle costs during operations.				4	4	**4.5**
Satisfied users of the building.			2	2	4	**4.25**
Buildings with better indoor climate.			1	6	1	**4**
Less stress and lower level of conflict.			3	2	3	**4**

Table 2 Interviewees' scores of the effect of systematic completion
(statements based on Johansen and Hoel, 2016; ranged according to descending average score)

Table 2 shows a unanimously positive picture with all answers in the range between three (neutral) and five (highly positive). Everybody agreed that SC in their project had a highly positive effect on the early detection of errors, avoiding costly rectifications at a later stage. The factors "better indoor climate" and "less stress" score lowest with a still high average of four, but the spread of the answers is different, as there is more agreement on a positive effect on indoor climate, while there was more ambiguity among the interviewees on the effect on the level of conflict in the project.

4.3.Discussion

SC is perceived as very positive by all interviewees. Negative issues are limited to acceptance problems and lack of full implementation. Nevertheless, there are nuances, as interviewees with a project management background perceive SC as a stronger cultural change than technical resources do. This indicates that SC augments a technical focus on completion with managerial focus. In this context, one might ask why SC has not been used before, if it so positive for a project. The findings give some indications: Because of split responsibilities in a traditional project execution, focus is on the project instead of the whole life cycle and especially the operation phase of the building. Narrow contractual obligations have been prioritized over a focus on functions and completion. This also entails a consequence for the professions involved in the project: Technical sub-contractors are involved earlier (during testing), and interdisciplinary technical coordinators are of higher importance than before. Also other stakeholders as the final users and especially resources from FM contribute with their competences and ideas into the project. A challenge might be that this requires additional effort, in terms of both time and cost. Additionally, SC requires a higher effort and more discipline in the early project phases. The results from the study challenge existing literature by promoting completion as an integrated process instead of a delimited commissioning process at the end of the project. The focus in the comprehensive process of SC is much broader than the narrow focus of commissioning often reported in existing literature, e.g. on indoor climate, energy efficiency or third party verification. The results also highlight the intertwining of project and FM, arguing for mutual benefits.

The findings from project documents and the interviews demonstrate the participants' clear perception of the positive effect of SC on project management performance: It assures successful commissioning of a building (c.f. Mills, 2011a, 2011b; Kalilieh, 2014; Schneider et al., 2016). Both commissioning and SC change the focus from building structures to technical systems (Forcada et al., 2013, Shirkavand et al., 2016). However, this can be perceived as problematic from a value management point of view, since focusing on technical conditions in the planning and construction process potentially can downplay the focus on the actual user value (cf. Bjørberg et al., 2017). Future SC literature would benefit from considering a value management approach. In line with Mills (2011a and 2011b), the present study indicates that the perceived benefits from SC outweigh its costs. According to the interviewees, the involvement of FM early in the project is a prerequisite for successful SC, as it increases value creation, ensures effective technical solutions and enables a smooth takeover of the building by operations. This is in line with the studies by Bjørberg et al. (2017) and Boge et al. (2018). It gives a holistic view of a building's life cycle beyond the construction project (Scarponcini, 1996) and reduces the problem of a bad legacy from the project to operations (Rasmussen and Due, 2019). Apart from the potentially subjectively positive impressions from the interviews, project data from the completed project 1 is a more objective indicator for a positive impact of SC: errors are successively eliminated (Atkinson, 2002), leading to fewer errors at takeover and fewer complaints at occupancy (Kalilieh, 2014). As perceived by the interviewees, SC fosters mutual learning and knowledge transfer when operations is involved (Jensen et al., 2019). The study also revealed the need for SC as an integrated and accepted process in order to give the full benefits. In contrast to the literatures' emphasis of a third party confirmation approach (Ellis, 2015, Hopps and Babaian, 2014), the building commissioner, the design team and the contractors apply completion as a management task throughout the whole project. This understanding is a result from the present study and illustrated in Figure 2. In contrast to SC, the traditional commissioning process is understood as the phase from mechanical completion of the building until handover, when the building commissioner accepts the contractor's work. In a project with successful SC and no major deficiencies at completion, takeover by operations can almost coincide with handover.

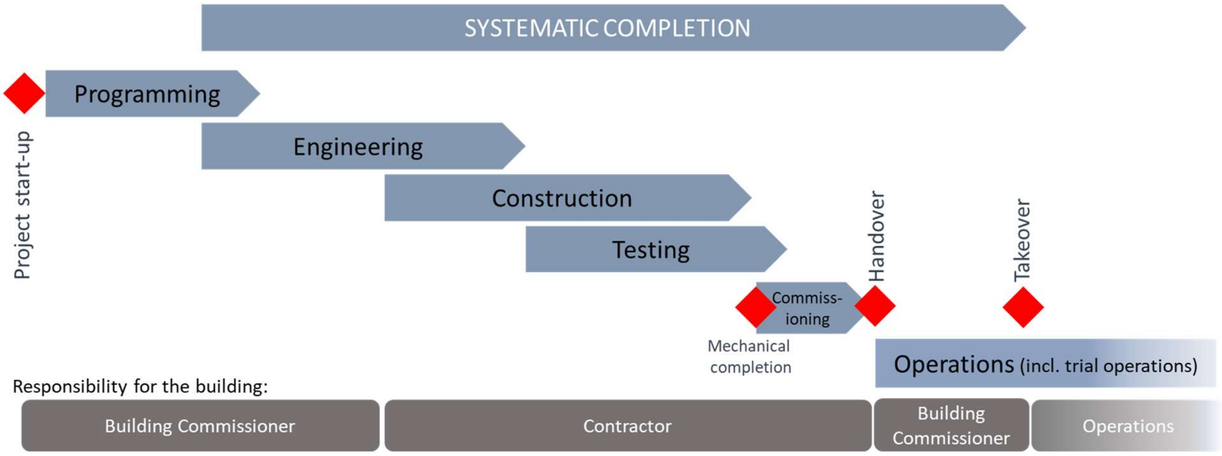

Figure 2 Processes, milestones and responsibilities in the completion process

The case study results indicate that a systematic approach to completion with clear strategies, requirements, test procedures and documentation as well as the inclusion of facility management personnel in the process has led to a less arbitrary completion process. Its integration results in buildings with fewer errors, which are operationally ready at completion.

4.4.Limitations, generalization and suggestions for further research

The qualitative character as well as the choice of projects and interviewees has implications for the result of the present study. A quantitative approach including a larger number of projects, also from other building commissioners in the public and private sector, might result in a higher degree of scattering of a perceived positive or negative effect of SC on project performance. Interviewing only people from the "SC-community" might have led to restrictions in critical responses, as they all have invested substantial time in SC. Further research should also include people in other positions with different perspectives.

This study can only provide a starting point into analysing the effect of SC. Existing studies have focused on the technical side (e.g. Nykänen et al., 2007; Turkaslan-Bulbul and Akin, 2006), not on its effect on project management performance. Further studies with more data, also in an international context, need to complement the present research. Taking the design team's, the contractor's or the customer's vantage points, would contribute to an improved insight on the effects of SC. Systematically measuring customer satisfaction and end user efficiency will be an important aspect to study when more projects with SC are completed. A quantitative approach can help to estimate the effects of SC on costs in the operation phase, e.g. by comparing energy data, cost of operations and change costs after project completion.

Even though the present study focusses only on one building commissioner, the results indicate a possibility for generalization, as central elements are in line with other studies: A systematic approach to completion/commission reduces errors at takeover (e.g. Mills, 2011a, Shirkavand et al., 2016). Collaboration and knowledge transfer between facility management and project management is essential to make it successful (e.g. Jensen, 2012 and Jensen et al. 2019).

5. Conclusion

RQ1. Which effect does systematic completion have on project management performance of public construction projects?

Those working actively with SC are convinced of its positive effect and its significance for completing a building within schedule, cost and quality. Savings through fewer errors, reduction of unnecessary costs and timely completion of the building offset higher investments early in the project due to more planning effort. SC also has effects on facility management as operations use less time and money for training and corrections, and there is a potential for systems optimization and energy savings in the operation phase through SC. This seems to be linked to a positive atmosphere in the project, fostering collaboration. Project 1 was completed on schedule, cost and with the defined quality with only minimal errors upon completion and high customer satisfaction. The building and all systems were smoothly transferred from the contractors to the building commissioner and to facility management without delay.

RQ2. What are the prerequisites to make systematic completion work?

The most important aspect to make SC work is the integration into the complete planning and construction process. Starting the process early in the engineering phase allows choosing a design apt for easy completion, writing good functional descriptions with corresponding test procedures, and including SC into contractual agreements. A systematic test regime is also an integral element. Transparent processes involving both facility management and the users of the building are essential. Formal structures in the project, such as a dedicated project manager for SC at a high level of the project hierarchy, as well as a strategy paper and procedures contribute to building up a project culture for SC.

RQ3. What are the learning effects from systematic completion?

SC fosters individual learning, especially by involving facility management into the completion process. A main learning effect is to start the process earlier, put more effort into planning and engineering, and draw on peoples' experience from previous projects. Table tests can reveal unsettled issues with technical systems at an early stage and should be prioritized in future projects. However, time use for preparation of and participation in tests has to be balanced and the level for details for time schedules can be optimized. Also on the organizational level, learning occurs, both as an exchange of experiences between projects, and between project management and facility management.

This article cannot conclude with a directly measurable effect of SC, expressed as a specific amount of money or a percentage of project cost. However, extra costs for error recovery are avoided. When applied fully, SC will have positive effects in the presented projects, especially on completing the project on time, reducing flaws and assuring a smooth transfer to operations.

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