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Continuous Improvement on Detailed Design Phase: A Process Perspective

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Abstract: The construction project being studied is a government investment related to the relocation of a biomedical institute delivering research-based knowledge and contingency support in the fields of animal health, fish health and food safety. The project covers a total of 63,000 square meters distributed over 10 buildings with a very high degree of complexity. The design alone has required 1 million hours, which relates to a client cost of about 100 million Euro. The purpose of this paper is to study the applied methodology for managing the detailed design to identify lessons learned from the project. The theory underlying the study is inspired by lean design management and design theory linked to design as phenomena, including reciprocal interdependencies, iteration, decomposition, design as a "wicked problem", learning, gradual maturation, etc. The article is based on an abductive research design and has been implemented as a case study where both qualitative and quantitative methods have been used.

Keywords: AEC-industry, complexity, design, lean construction.

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1. Introduction

The concept of design in this paper includes both architectural and engineering design. While the design processes in construction make up a relatively small share of construction costs (about 10%), they are integral to the building's life cycle, including customer value, maintenance and operational costs (Evans et al. 1998, in Gilbertson, 2006). Koskela et al. (2013:9) regard the design-production as a chain of processes where "value is created as a potential in design, is embodied in production and is realized in the intended use by the client."

The management of the design process itself, however, is more complicated than the management of the production phase due to characteristics such as iterations, gradual maturation, learning, reciprocal interdependencies (Thompson, 1967) and the often-fragmented design process involving several different consulting companies, the client and construction companies as well as their subcontractors (Kalsaas and Moum, 2016). According to the Lean tradition, the management of design processes is often designated as Lean Design Management (LDM), e.g. Koskela et al. (1997) and Uusitalo et al. (2017).

In order to achieve efficient design management, we need knowledge of design as phenomena, structured work methodology and feasibility. This paper develops and builds on a master thesis (Rullestad and Thorud, 2019) and (Kalsaas et al., 2019). It studies one of Norway's largest onshore AEC projects, which has a high degree of complexity. The aim is to study the structure of the applied management method in relation to design as phenomena with the aim of uncovering potential improvements and lessons learned.

First, the method will be described followed by the theoretical framework and finishing with an analytical model that is used as the basis for the empirical analysis. The findings are described according to the analytical model before they are drawn into the discussion. Finally, lessons learned are summarized and brief comments are made on the validity and application of the theoretical basis.

2. Method

This research deals with a single project and therefore the most obvious research approach to choose is case study methodology as well as most appropriate. We were inspired by Sayer (1992) concerning critical realism (theoretically informed) case studies, then supplemented this using the case study method. The study is primarily a contextual analysis in relation to explaining obstacles in the design work (lessons learned). In terms of structure, it is in the incentives associated with the applied contract strategy (design-bid-build). We consider incentives as a structure that together with mechanisms can lead to certain outcomes, given certain conditions (Sayer, 1992). Qualitative data collection was conducted using semi-structured interviews, of which two were with representatives from the client's project administration and eleven with the design team management. Quantitative data collection was conducted using a survey.

This paper has been organized in the following manner. Firstly, the researchers acquired relevant literature which worked as a foundation for further work, which is backed up by Creswell (2009). Then, an interview guide was established with specific topics of what the researchers wanted to obtain information about. Thereafter, semi-structured interviews with key actors and leaders were organized whereas the interviews were recorded. From there, the empirical data was combined and contrasted with the developed analytical model and theory. Furthermore, the survey was conducted to ensure that the findings from the interviews were representative of a larger population.

A total of 14 interviews were conducted with key individuals from the client, the design group and the construction management, whereas 11 out of 14 informants came from the design group. The informants cover the following roles; different design disciplines, project group coordinator, project manager design, contract manager, quality manager, architect, discipline manager construction, discipline manager Heating Ventilation and Air Condition (HVAC), discipline manager electrical, BIM coordinator, digital interaction manager, progress planner and client advisor for user values.

3. Theory

3.1. Complexity

What is project complexity? It is widely agreed that it includes more than just project size (Williams, 1999), but beyond that there are several perspectives (Johansen et al. 2019). The International Centre for Complex Project management (2012:22) defines complexity to be characterized by a "degree of disorder, instability, emergence, non-linearity, recursiveness, uncertainty, irregularity and randomness, and dynamic complexity where the parts in a system can react/interact with each other in different ways." Rolstadås and Schiefloe (2017) identify the most significant complexity drivers to be ambiguity, uncertainty, unpredictability and pace in their project complexity model. The model also includes complexity factors, which are the components involved that are produced by the system. Moreover, where each component has attributes with relationships and interdependencies. Whitty and Maylor (2009:305) describe a complex system as "a system formed out of many components whose behavior is emergent," which we may relate to the "complex" domain of the Cynefin framework for complexity (Snowden, 2000). The Cynefin framework has four main domains: simple, complicated, complex and chaotic. In the simple domain, cause-effect is well known, and we are in an area where, for example, linear planning will work. In the complicated domain, cause-effect can be derived by means of expertise (sense-analysis-response). For the complex domain, one does not know the cause-effect until afterward. It emerges (probe-sense-response). The fourth domain is termed chaos by Snowden (2000). There you have lost control and it is about doing something to try to stabilize the situation (act-sense-response).

Ballard and Koskela (2013) link the works on rhetoric and design by Kaufer and Butler (1996) to the concept of "wicked problems" (Churchman, 1967). Moreover, because of complex interdependencies, the effort to solve one aspect of a wicked problem may either reveal or create other problems. The phrase was originally used in social planning and is contrasted with "tame problems," which are more linear in nature, where the concept of cause and effect is well known, as in the "simple" domain of the Cynefin framework. We moreover may relate wicked problems to the "complex" and "chaotic" domains. In the context of this paper, it is a point that if you plan and organize a project as if you are in the simple domain, and this does not prove to be the case, then you easily fall into the chaotic domain. When regarding design in complex projects wicked and conceive learning to be central, the management of such projects is certainly challenging.

3.2. The Phenomena of – and the Management of Design

The purpose of design is to transfer enough information about the designed artifact so that it can be manufactured, fabricated, or constructed (Gero, 1990). Gero, moreover regards design activity as a goal-oriented, constrained, decision-making, exploration, and learning activity that operates within a context that depends on the designer's perception of the context. Gero and Kannengiesser (2014) are modeling the design process by starting with the requirements, which lead to functions to be designed. From function to the description of the design (output) there are iterations and decision making related to the expected behavior of elements, its wider structure and behavior derived from structure. Hence, there are several possible design outputs from functional requirements. Ballard and Koskela (2013) criticize the analytically inspired design theory by Gero (1990), and argue it is incapable of handling aesthetic impacts in the initial exploration of the design problem, which is claimed to only be covered in rhetorical inspired design theories.

Koskela et al. (2014) refer to the concept of iteration in design arising as a new idea in the 1980s based on the observation that when working, designers jump between goals and means instead of following a linear path. Regarding the method aspect of project realization, a significant shift came with the arrival of agile methods in software development (Schwaber and Beedle, 2002). As a phenomenon, Kalsaas (2020) characterizes design in addition to the complex and iterative, with learning, gradual maturation and reciprocal interdependencies. The article assumes that Management of design must take an understanding of design as a phenomenon, which means that linear planning will rarely work unless we are in the Cynefin framework's simple domain. Iterations and linear planning do not fit well.

Last Planner System (LPS) (Ballard, 2000a), a well-known process-oriented method for production control in Lean Construction, which is based on five principles. These are highlighted by Ballard et al. (2010) as 1) Plan with greater detail the closer you get to the specific execution; 2) Plan with those who will do the work; 3) Identify and remove obstacles for scheduled tasks in teams; 4) Make reliable commitments for work to be carried out as agreed;

5) Learn from cases where problems with the implementation occurs. Ballard (2000a) argues that LPS is also an appropriate method for design management. Kalsaas (2020) finds that LPS is useful, but that you need something more to deal with the iterative nature of the design. This finding makes Kalsaas (2020) propose a methodology where Scrum, which is an Agile method, is used in detailed design management for complex design projects.

LPS has fundamentally been inspired by the process-oriented Transformation Flow Value (TFV) theory (Koskela, 2000) which is a production theory related to lean production and lean construction. In this theory, production is seen as a flow of transformations that create value in the form of a product. Transformations are the traditional focus on production, while Flow and Value are the new perspectives. Koskela (2000) links value to the quality movement, where value is implied as customer value. To remove waste and continuous improvement are two central values of the flow part. Ballard (2000b) introduces the term negative iterations in design to describe iterations that do not create value but waste. An example is if a designer works too far in his discipline without coordinating with other disciplines, and thus must do the work again. Virtual Design in Construction (VDC) is related to the flow and process focus in Lean (Fischer et al. 2017), and has an integrated approach to product, process and organization. VDC address BIM and related processes, where Integrated Concurrent Engineering (ICE) is a well-known concept for working with reciprocal interdependencies in design

3.3. Creation of Customer Value in Design

Johansen et al. (2019) differentiate between "project goals" and "business goals" in project management. Project goals are the traditional goals of delivering the project within the budget, time frame and according to the client specifications. Textbooks in project management refer to these goals as the iron triangle. The business goals include the values for the customer which exceeds the iron triangle. The customer term includes the project owner, the client and the users. It might be some tensions between the two sets of goals, because to achieve the business goals it is called for the postponement of certain decisions in order not to miss out opportunities for the users. That could be decisions regarding which technological equipment a construction should be built for, which may have a strong impact on the detailed design process regarding the supply of energy, information technology and HVAC. Hence, late customer decisions complicate the design management process when addressing the project goals, and late client decision is often regarded as a disturbance for project management (Kalsaas, 2020).

In the context of project flexibility and lean construction Ballard and Vaagan (2017) discuss that flexibility in plans usually can be achieved by a combination of postponement and hedging. To handle postponement, as addressed above, a possibility is to apply the "decouple point" concept by developing a "two-stage planning process", where the decoupling point defines the degree of customization (Robertson and Ulrich, 1998). To hedge is to try to avoid or lessen a loss by making counterbalancing investments, according to Webster's New World Dictionary, College Edition, published in 1968 by the World Publishing Company. Ballard and Vaagan (2017:593) exemplify hedging with set-based design to "develop a fallback alternative design in case it is needed to meet the Last Responsible Moment" (Ward et al. 1995). Hedging complies also with the Last Planner System regarding the principle of planning more in detail as you approach execution when more information is available (Ballard, 2000a). An example of hedging is to exaggerate structural dimensioning when the loads are uncertain. Investing in different design prerequisites will have a cost, which can be calculated and compared to the cost of waiting until the selection is made.

Target Value Design (TVD) is a management approach applied to create customer value in construction within a framework of budgeted constraints (Miron et al. 2015). Koskela (2000) considers the TFV theory as a baseline to understand value generation. In TVD it is designed to a financial target, using several iterations, rather than estimating a pre-decided detailed design (American Institute of Architects, 2007). Ballard (2011) relates TVD to relational contracting but it can also be applied in a transactional approach to contracting. Related to user value, Choosing by Advantage (CBA) is a method used in TVD-inspired design management (Arroyo et al. 2016). The method is aimed at systematically uncovering the most important value for users. A distinctive feature of the method is that costs associated with alternative solutions are deducted after the values have been clarified. This is so that the cost focus doesn't hinder the value discussion.

4. Bridging Theory and the Case Study

Reciprocal dependencies are fundamental to understanding what kind of phenomenon design is. These often play out in one or, often, multiple iterations. Reciprocal dependency drives iteration in conceptual design, as the conversation between interdependent specialists must go through an indeterminate number of cycles to achieve alignment. Iterations can be linked to the Kolb's experiential learning cycle (1984), where each loop represents a test, observation and reflections before identifying needs or desires to make a new iteration. The coordination mechanism for reciprocal dependencies is a mutual adjustment, but if we have reciprocal dependencies then there are always also sequential dependencies present, where plan is the coordination method, according to Thompson (1967). Design in complex projects can be considered a wicked problem, and as such there is no logical end for when the design is finished as it always can be improved by another iteration.

What is important to look for when evaluating the design aspect of the project with the aim of uncovering lessons to be learned from? We have presented this in Table 1, which we can consider as an analytical model for the empirical analysis, inserted into the theoretical basis that is focused on above.

Table 1. Analytical model

Aspects of design to be evaluated	Comments
Complexity	The complexity of the project provides prerequisites for organizing and choosing, for example, coordination methods.
Organization - collaboration	Obviously, a project must be organized in a way that is proportionate to the tasks to be solved. In addition, a collaboration between actors and disciplines is central to solve complicated tasks.
Iterations; Problem-solving; Reciprocal interdependencies	Did the project use appropriate methods and techniques to deal with these properties related to design as a phenomenon?
Learning - gradual maturity	Did the project use appropriate methods and techniques to deal with the gradual maturation that occurs through iterations and learning?
Interface design - construction	The production is conceived as the customer of design and has a significant impact on constructability.
Value creation – user processes	User processes are central to the client's value creation perspective.

5. The Studied Case

The AEC project being studied is a conglomeration of a faculty of veterinary medicine and an independent national biomedical research institute delivering research-based knowledge and contingency support in the fields of animal health, fish health and food safety. As a premise for the construction project was a relocation of both institutions to an existing agricultural university. The decision was made by the government in 2008. Included in the decision was a merger of the faculty with the university, which was implemented in 2014. The research institute is independent.

The construction project comprises 63,100 square meters, which is distributed between ten buildings. The project budget makes up 800 Euro of which 100 Euro for the user equipment.

A government administrated company is the client of the project, and it is organized as a design-bid-build (DBB) with a total of 40 execution contracts. In relation to the design process, there was a group of four consultant companies that won the contract together. Within the design team, there are design managers, architects, landscape architects and discipline representatives from construction, electrical, HVAC (Heating, Ventilation, and Air Conditioning), fire prevention, acoustics and building physics, as well as 11 different special disciplines such as Infection Control, laboratory design and external environment. The project started in 2010, where the detailed design was carried out from 2013 until the start of 2019. About 200 architects and engineers have worked with design in total, whereas 120 worked simultaneously at the most. The planning group has been co-located since the start of the detailed design and moved to the construction site in August 2018. The construction period went in parallel with the design process, starting in 2013 and completion scheduled for 2020.

6. Empirical Findings

6.1. Complexity

The project is one of the most complex construction projects in Norwegian history, according to respondents. One respondent points out that very few of the project's 2466 rooms are the same, and that it only exists from one to five of very many of the rooms. This means “that there is a small degree of standardization potential” and that only laboratories and offices (30% of the area) possess a degree of repetition. In many other areas, there is tailoring at the room level. One respondent believes “many have miscalculated the complexity of the project, even though many have drawn hospitals before”. The client representative confirms that both they and the design group underestimated the complexity. A representative from the design group points to complex plumbing installations that are related to infection control, “we have 80 ventilation systems with different functions to supply the rooms.” The deadline has been very overbearing and “the design just had to be completed. It had to be done that way with the time we had available.” Furthermore, this is a full-fledged hospital, with many operating rooms, special requirements for examination rooms, X-rays, CT, etc. “We have had evenings where we cross-checked drawings and action lists to get everything in place.” Managing infection control requirements and knowing that there is control of an infection situation has been the governing factor for the entire project, according to several respondents. However, it is shown that “everyone in the design group has solved it differently in different places.” Furthermore, in relation to lessons learned, one respondent states, “Someone should go ahead and say “so it is” as a framework condition. We have not been good enough at drawing in principle. Structure and generality should have been planned much earlier. It should have been created several examples and prototypes of how things should be done in advance. Furthermore, it should have been specified and predefined which products to use and how the different guides should be compared to each other for the different types of rooms, to ensure that everyone knows exactly how to do the project and that things are done the same. When one group solves a problem that another group could benefit from, the solution should be archived and made available to others. Another respondent claims that “a great deal of frustration could have been avoided if we had a facet.” He points out that if they had only spent one day a month updating a design manual, the process would have improved.

6.2 Organizational Aspects

6.2.1. Detailed design before bid

The design process was mainly managed according to traditional principles. There were organized weekly design meetings and the earned value method was used to measure progress, and a design plan was prepared in Gantt. Figure 1 shows how the design management in the case has presented the overall schedule for the detail design phase. In the context of progress, it was planned in detail longer than 6 months ahead.

From start-up to detailed design and until completion, it was planned according to area design. Each of the ten buildings in the project represented its own sub-schedule, led by its own area team and with its own administrator in addition to representatives from all the disciplines. There has been an overall BIM coordinator for the project, in addition to a BIM coordinator for each of the disciplines. Lean processes were initiated in the detailed design phase, approximately half a year before the bidding, when a Lean inspired actor with Virtual Design and Construction (VDC) certificate joined the design team. One of the measures introduced was Integrated Concurrent Engineering (ICE) meetings.

6.2.2. Follow-up design

In total, the project was divided into 40 different execution contracts. After the offers were picked up, the client chose to change the structure and redesigned the hierarchy as a contracting organization. Most design disciplines managed between 1-5 contracts each, while HVAC had 16. The design team moved out to the construction site in August 2018 and redistributed the organization around six "fronts" which are interdisciplinary, while the contracts are specialized within each discipline. Each front represented one or more buildings, and within each front, there was a leader in addition to representatives from both the design group, the client, the building management and the contractors. One of the purposes of the reorganization was to facilitate problem-solving in design in interaction with those on the construction site. Later, it was decided to go back to the contracts divided by disciplines, while retaining the "fronts."

In summary, the design was first organized as site design for buildings, then it went over to being designed after contracts divided by disciplines, then it went back to being designed after buildings in the form of "fronts", and then it went back to contracts divided by disciplines with the "fronts" still kept.

6.2.3. Other findings – organizational aspects

When asked if the client has been involved enough, one respondent replies that "no, not really." The respondent thinks "it is strange that they do not control it to a greater degree" and points out that there are many hired resources in the project. Another informant points out that there has been too much designing and building in parallel, and further that construction work was started too early or that the designers "did not get deep enough into the matter before construction started." One respondent from the client acknowledges that they started the raw construction contract too soon before the room programming was completed. This was done to reach an end date with the school started in 2019, which later turned out not to be realistic.

Interview data further confirm that the contract model has been challenging due to a large number of site contracts, which has provided demanding interfaces in designing a solution between the site contractors. Furthermore, an informant points out that a large number of site contracts "has allowed the site contractors to blame each other." The design group proposed a simpler contract structure with larger contracts and clearer interfaces, but the client wanted it this way and "it is their right to decide." As a contribution to explaining the chosen solution with many contracts, it was claimed that the client was "very scared of the market." The data also shows that the designers experienced that the decision to subdivide the contract was made late, making it difficult to follow up on the facilitation of design interfaces.

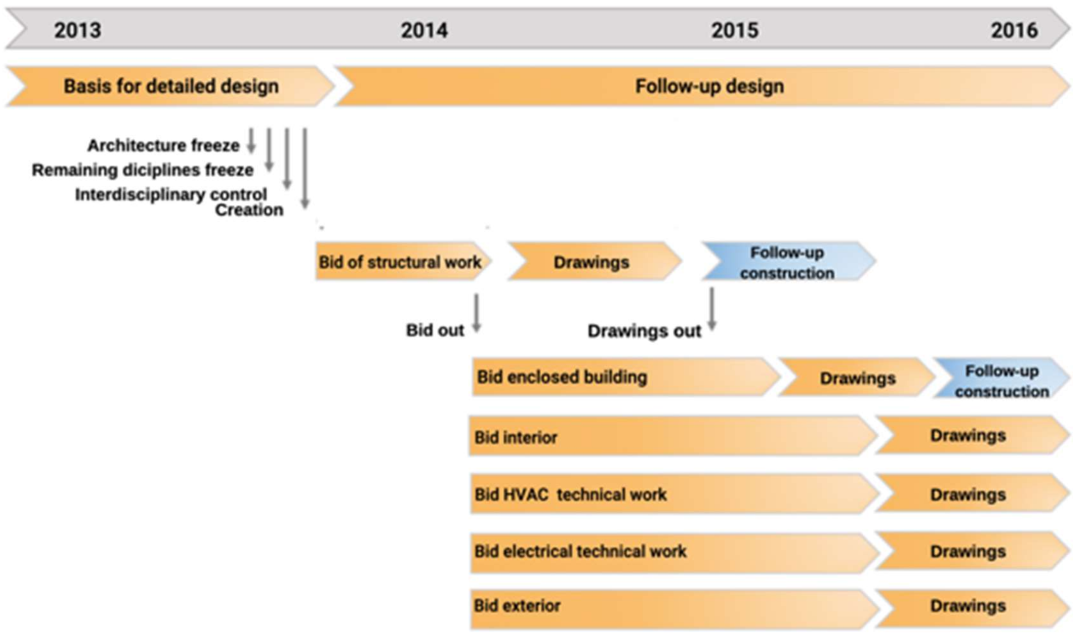

Fig. 1. Illustration of the strategic schedule for the detailed design phase

One respondent emphasized that he agreed with the choice of design-bid-build (DBB) as a contract model, "because the contractors had zero chance to understand all the functional requirements" that would have been necessary to work according to the design-build framework. It was further pointed out that many of those working on the project "have never worked this way," and that they have therefore not realized that "if you need a screw on the wall, you have to describe it." It was argued that the site contractors do nothing but what is drawn. "It took a very long time before we were able to get that understanding into the designer group, and many designers never got it."

The database further shows that the following up-design phase has encountered problems in the way that people from the site contractors approached different designers regarding the same problem. Hence, the designers, in turn, worked to solve the same problem in isolation from one another.

An organizational approach that appears to have negligible drawbacks is the co-location of the designers together with the client at the construction site, according to the client representative. They postponed getting the design team to the construction site as the commuting costs were not included in the contract. The client moved to the construction site in 2016 when construction was well underway, while the design team did not arrive until 2 years later in August 2018. The respondent felt that co-location should have been done at the first construction day. The benefits are related to communication and proximity when reciprocal dependencies are to be coordinated (mutual adaptation) and the possibility of concurrent engineering.

6.2.4. Reciprocal interdependencies – Iterations – Problem-solving

According to informants, the biggest challenge has been that the designers did not get to properly project the interfaces. The reason is linked to late decisions. It has been pointed out that the user process had been under dual criticism from both the design group and the client. It has been "very bad", says a design group representative, because "there has not been one user from the users who have controlled the process on the part of the institution. Even the principal is included. Every field of study has governed its stuff and it has always been "redraw and redraw". No one froze the design. Thus, we took the users too far in the process. At the same time, the user is very important as they are the only ones intimately familiar with their needs. None of the designers have experience with this type of project, which means that we have to work with the users to find out how to do it."

It also appears that users need time to reach an informed decision. One respondent further argues that "we should have had the user process a long time before we started to detail design." The client's respondent also points out that the user process started too late. The database (dRofus), where all information is supposed to be, "has been disastrously bad," according to a representative from the design group. "It is a good program, but it has been used incorrectly from day one. The size of the project means that we must do things right the first time, because "no one notices it if you make a mistake before it is too late."

The project's long duration is also identified as a challenge in addition. A respondent argued that as it goes on for so many years, new leaders were recruited to the user groups, and they sometimes had very different ideas of how things should be compared to their predecessor. Such changes are claimed to have generated much "noise." A representative from the design group argued that "there has been a problem in the project that the User Equipment Group together with the users agree to change a part of the concept." Usually, a change message should then be sent, which the design manager must approve or send to the design group where the consequences for the chosen solution are investigated. However, the user equipment group often did not say anything or just called an architect, and suddenly there is someone working on something that has not been collectively decided upon for initiation. The client representative points out that they have had some useful tools for managing digital information flow and highlights the use of a project hotel.

6.2.5. Learning – Gradual maturity

The data shows that methods for measuring maturity in BIM have been used. The method referred to is the status setting in LoD (Level of Development) (Grytting et al. 2017). However, a respondent expresses doubt whether the maturity levels have been defined correctly. A design manager points to "gut feeling and experience" as the applied method to handle maturity levels across disciplines.

Furthermore, it appears that what is particularly challenging is the impact of discipline lagging. HVAC is the discipline on the project with the most complicated engineering design challenges related to infection prevention and control. The discipline was lagging the schedule due to a shortage of competent people in this very specialized area of HVAC.

An informant explained: "As a result, we have not been able to make technical decisions at the right time. We have had cases where the architect and electrical team have requested clarifications from HVAC, which HVAC has not been able to supply. The architect and electrical have then moved on based on assumptions that, in some cases, have turned out to be erroneous. So, then they must backtrack and re-do. Obviously, this is "very costly for both the client and us and it creates some noise in the organization," according to gathered information. This creation of waste is an example of a negative iteration.

Several respondents claimed that the "major challenge in this project is that we failed in reconciling the room-function program until we started the detailed design. The room-function program should have been available when we finished pre-phase design, such that "we had an agreement on what is to be built in relation to user needs". The next step for the design team would then "be to translate the functions into technical solutions". Moreover, was it explained when "we discuss technical solutions and functional needs in parallel a lot of extra time-consuming iteration processes occur". A respondent finds it strange that they every day for 8.5 years have been in such a hurry and explain that "we just needed to rush to finish assignments because there were always such short deadlines". Hence, "we have never had time to go back to reflect on the dependency between what we have modeled or projected in the different buildings."

Several designers denoted they have learned a great deal in the project, and one respondent pointed to the example where they decided what was "good enough" design and communicated the freeze of design to the client, which worked. To take advantage of learning for the next project an informant points out that when "we start a new project there are different people in the team and we go full throttle from day one. Strange, but we don't take the time to learn from experiences in the previous project as time is always conceived to be a limited resource." A design manager added that it is "common in our world that we have to invent the wheel every time".

6.2.6. Interface design - Construction

"We have experienced that we have received feedback from the contractors that our design has not been buildable", according to an informant. It appears that in some areas the design has become very tight and not optimal. The informant exemplified it with a shaft 1) original plan was 4 sqm for a shaft; 2) the shaft was reduced to 3.5 sqm to give space for a safety station that was not taken into account; 3) a wall had to be moved due to lack of space for linings, and the shaft ended up to be 3 sqm. Furthermore, it was said, new requirements came from the user, resulting in the need to install cooling pipes or heating pipes in the shaft. The limited space for technical installations means that the design takes a very long time, which was expressed to be a "struggle for us".

There have been many "collisions" during the design, which was explained by great complexity. One informant says that the "worst example" was that in one example layers of pipes occupied all space available and then blocking access for other functions. The informant reflected on reasons by pointing to a lack of experience and silo thinking by designers and identified time pressure as the root cause.

It was pointed out that it became a greater focus on facilitation for buildability when the contractors arrived on the field, and together with the contractors "we have reviewed the 3D-model and identified and sorted out problem areas". The data reveals moreover that operational scheduling in design and production was conducted in two different software programs. Both programs were within the Critical Path Method family. But the most serious challenge is that these plans were not interconnected, according to a production planning respondent, who characterized it as a "serious error". He argued that "we got some interfaces that were terribly difficult" to handle. The challenge was related to the problem caused by designing per building and missing out the interface connections, confer the example also commented by a designer respondent from design.

6.2.7. Value creation – User processes

This project is a functional specified project, where to meet the function decides whether the project is successful, according to a respondent. It was added that, what we build is worthless if the users and the customer cannot utilize it, and it was claimed that the "users have almost had the exclusive right to define the requirements for the functions."

Respondents have interpreted the goals of the project to build "the most modern animal hospital in Europe", which makes it "natural for users to want the latest of the latest in technology." Moreover, "with the momentum of development today, you have to wait until eternity if you want the latest of the latest, and that is what the users have done," according to a designer. It is claimed that the design team was able to handle the late user changes, but that it resulted in the time-consuming design and the process became sub-optimal.

A designer claim that everyone has been a little disappointed that users have been in the process for too long and elaborates that to discusses "how" with users is always acceptable, but not "what". It is experienced that the designers have had discussions late in the detailed design on, for example, temperature control requirements in individual rooms. The problem with this, according to the informant, is that it comes when the systems for heating and ventilation are already designed. Another example that is addressed in the interviews is that the users in detailed design may influence the location of the equipment but not which equipment to select, which "must be programmed." "It is probably here that we have had the biggest challenge in the project", according to respondents, and that "challenge becomes particularly severe when we have limited space available and few similar rooms." Also, the client pointed out that the process with the users should have been better structured and planned from the start, and that the decision-making systems, responsibility matrices and schedules should be improved.

With respect to customer value, it was pointed out that this is such a special project that often the user had to see the solution drawn before it was possible to decide. There was a lot of trial and error in that process. An informant points out that a section of 3000 sqm was completely drawn out 19 times, and that each iteration took 2-3 weeks. During this process, new people and new input continued to emerge, and different academics wanted to prove their expertise is one of the claims. This turned out to prolong the design process, and the designers missed an authority to say what "is good enough."

"The project's infection prevention and control concept has finally become good and robust", according to a lead designer. Regarding operation and maintenance, it is stated that there has been a challenge in the project that the access to technical equipment has turned out to be limited due to tight technical solutions, confer the example above about the stepwise space shrinkage of a shaft. A respondent put this in a life cycle perspective, "these buildings are likely to stand for 100 years, while the technical components may work for 30 years".

7. Discussion

We start the discussion by addressing reciprocal interdependencies, iteration and problem solving that are fundamental to understand design work as a phenomenon in our theoretical framework, and we will end with complexity and customer value. This is because what happens within the first aspects is important for understanding the overall complexity that has been faced in the design part of the project.

The data documents many examples of iterations and problem-solving. As mentioned, a 3000 sqm section was designed about 19 times in interaction with the users. Terms such as "rewrite and re-do" are used by informants. The database shows iterations generated in the user process, but also several instances of reciprocal dependencies between design disciplines. Such as when HVAC is unable to deliver the basis for architect and electrical on time, and these disciplines continue working based on assumptions that subsequently prove not to solve the actual problems, and therefore must go back and re-engineer based upon the new requirements. It is also an example of negative iterations, where the work is not adding value.

When the developer halves the area to be built without significantly reducing ambitions in terms of functions, it results in many additional iterations. The same applies when at the start of the project they operated with an unrealistic date for completion and tried to speed up the progress of outsourcing incomplete contracts.

With a small exception regarding the use of concurrent engineering techniques in part of the project, the design part of the project seems to be planned and controlled with linear methods at the tactical and operational levels. Experience and theory show that it works poorly since the design is iterative by nature due to reciprocal interdependencies, and where learning and gradual maturation are an important part of the design phenomenon. At the strategic level, planning has been more appropriate for the division into multidisciplinary fronts, but it has missed at the strategic level when it comes to safeguarding dependencies between buildings, where the foundations are mentioned specifically in the data.

About gradual maturation, LoD has been used in relation to BIM, but this appears to have been unsuccessful. In particular, the data show that HVAC has not been able to deliver on time. It is true that no system will work if the necessary technical/social processes around fail. Processes for achieving systematic learning and measuring the quality of processes in the design phase appear to have been absent. The project does not seem to have had any strategy for this being important, but the data also shows that the designers have experienced extreme time pressure for 8.5 years. It may in short term be counterintuitive to spend time on learning and administration, however from a longer project perspective, it may result in less stress and "firefighting" and higher quality.

In the design-building interface, there are examples of solutions that are delivered that are not buildable, with buildability coming more into focus first when the contractors came in place. The data shows that the organization of follow-up designs in relation to the contractors has been inadequate, where there are examples of designers working to solve the same problem unbeknownst to one another. This is partly attributable to contract follow-up at the single-discipline level. In addition, problems may easily emerge when conducting concurrent design and construction without integrating planning and production plan.

With respect to organizational aspects in general, the large number of site contracts in a design-bid-build setting has been demonstrably challenging in terms of interface and coordination. This is such a specialized construction project that any design-build solution is unlikely to be a good solution, which a respondent justifies with the difficulty of understanding the specification. On the other hand, the chosen model is hardly optimal with such great demands in the project for new knowledge and related risk. However, there exist execution models that are more partner-oriented with risk and profit-sharing, see for example Kalsaas et al. (2018) that have greater potential in this regard. The more specific factors regarding the complexity of design are listed in Table 2.

Table 2. Project attributes of complexity for design

Attributes of complexity	Comments
Prevent and control large infection risk located in an important agricultural area. The goal of minimizing environmental impact	Knowledge demanding. Limited experience in the design group
In addition to the traditional design disciplines in construction, the infection, medicine and environmental issues engaged 11 different disciplines	Demanding regarding coordination of reciprocal interdependencies, gradual maturity, etc.
At peak 120 designers and experts worked in parallel	The number of designers increase the scale of complexity regarding the aspects above
40 execution contracts, of which several in the same trade (e.g. HVAC) delivered to different companies	Demanding regarding coordination. HVAC is the discipline with the most complex challenges regarding infection risk
A split between responsibility for detailed design and construction	Follows from the design-bid-build contract strategy. Increase the challenge to achieve smooth flow in the interface between design and construction to achieve high level of constructability
Tight time schedule for delivery	Add to complexity

Analyzed in relation to the complexity model of Rolstadås and Schiefloe (2017), as referred to above, we see that of the most significant complexity drivers, pace and uncertainty have largely been present. Uncertainty over opportunities that lie in new technology to create a world-class animal hospital. Unpredictability is also present in the way that the designers have not had deep expertise in what is to be designed and have depended on the users. Ambiguity has not been a challenge as the goals for the project seem to have been clear all along.

In addition, several complexity factors have been uncovered, including the interface between the building and technical equipment, handling of infection control, etc., which is elaborated below. An important factor about surroundings and complexity is the owner/builder's reduction of the building volume on several occasions without being reflected in the reduction of functions. The reason for the reductions was financial. In relation to the natural conditions, the location of a rich agricultural area is a complicating surrounding factor.

About the Cynefin framework, the project appears to be already in the complex domain as a starting point for interfaces between HVAC, electro and automation related to infection prevention and control. The same applies to building and user equipment. For example, no MR machine has been built for horses and a treadmill for dogs in Norway before. Other aspects that have increased complexity during implementation:

- Unrealistic completion date generated also premature start-up of detail design
- Too rapid start of construction compared to the maturity of design
- Simultaneous design and construction without integrating planning and management between design and production
- Defective database of solutions
- User processes without clear coordination and application of opportunity management, where an important incentive from the users is to get the latest in advanced technology in an area where development is moving fast
- Use of linear and deductive planning and management tools in the operational phase (Ganttplan / Critical Path Method)
- Lack of capacity in some disciplines, especially HVAC

Based on the system logic in the Cynefin framework, the level of complexity indicates that several processes were situated in the complex domain, and it can be assumed that design processes also were visiting the chaos domain due to the simple approach to planning and scheduling in the operational phase. The fact that the design project started with a budget of 350,000 hours and ended up with 1 million hours is also telling about the underestimation of both the complexity and scope of work.

In relation to customer value, it seems that a robust project is being delivered in relation to the overall infection prevention and control focus. The data, however, gives an indication that the operation and maintenance of the technical facilities can face challenges due to tight solutions with poor accessibility. Another aspect of customer value is that the designers depended entirely on what the users identified as their needs. Compared to more common projects, this can be a limiting factor for customer value, as there does not appear to have been any expertise available to advise users. It can be argued that this mechanism is aimed at investing in "more of the same." The large use of resources in design is something that must be paid for by the client, but the data also shows that the client must take part responsibility for a rather chaotic process. About three-quarters of the project's total reserve of 100,000,000 Euro was used during the design phase, according to the respondent from the builder's side.

The user process has been quite unstructured in the project, and several respondents point out that the biggest problem has been that the room-function program was not frozen from the pre-project before starting the detailed design. It would probably have made the situation simpler operations wise, more transparent and linear regarding the project goals (the iron triangle). However, what may be underestimated is that this project is completely at the forefront of innovation regarding business goals. Early freezing of user equipment would probably have reduced the project's scope for customer value related to having a world-class animal hospital delivered. For example, by examining the literature on risk and opportunity management (Johansen et al., 2019), one can compare parts of the project with research containing significant elements of learning, testing and uncertainty. It takes time and is a wicked problem per se. There is no best solution, but several good ones, and there is no natural ending. Rather, the project's problem has been that it has not been rigged to handle such processes in a structured way, and thus has been well away from modern thinking about opportunity management, as well as VDC and the lean perspective on integrating product, processes and organization.

8. Conclusion

Below are some key points about lessons learned in the case project. However, it is important to study the details above to get a deeper meaning around these points.

- Evaluate the complexity and uncertainty structure (opportunity and risk) of the project in a different way from what is done in this project. Consider the use of the Cynefin framework as a starting point.
- Choose an implementation model with respect to expected complexity and uncertainty. Consider relational contract models than design-bid-build and design-build.
- The more complex the design is, the more important it is to build relationships and trust across actors and disciplines.
- Plan a structure for decomposing the project at a strategic level that addresses all important interfaces.
- Integrate planning and management between production and design, particularly when designing and building in parallel. Production is the customer of design.
- Choose planning and management methods at the tactical and operational levels that have the capacity to handle reciprocal dependencies and iterations. Look for examples to Lean Construction, Virtual Design in Construction (VDC) and agile methods.
- It is positive to have the room programming done before the design part starts to achieve the project goals, but in such a complex project as studied, it may not be desirable for all the functions due to the learning and research dimension around achieving the business goals, the customer value.
- Incorporate routines for systematic learning across disciplines during project implementation.
- Standardize solutions to similar design problems.
- Attempts to gain a better structure for the user processes than documented here but keeping in mind that learning and change (uncertainty) can also be something inherent in the complex. The planning and management system should, therefore, have the capacity to handle change. Change is normal.

- Consider using the Choosing by Advantage method to help increase customer value and structure of user processes.
- Co-location of the design group, the client and contractors at the latest when construction has started. Early involvement of the site contractors in the design phase is beneficial for buildability. It is important to contract and budget the extra cost of co-location.

The validity of the data is somewhat limited as it lacks data from the users and the contractors. Compared to the users an advisor from the client's user processes weighs up positively, which is also the case on the contractor side, as a production planner was interviewed. The data collection has mainly been done over three months and you do not get all the aspects in such a short time on such a large and complex project, but the informants come from several positions within the design group and the client's organization, and most have the first-hand experience over a long time in the design phase. Therefore, there is a reason to trust that the data has a good enough validity to give a true picture of the project's design portion, especially from the perspective of the design group and the client.

The theoretical basis of the analytical model is perceived as fruitful for analyzing the design part of the project, but the work is also a reminder that to understand complex projects it is important to have a holistic approach, since the aspects that are used in the analytical model are largely related to each other. That's why a total understanding comprises both the aspect that is under consideration as well as how the aspect is linked to other aspects of its environment.

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