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TOWARDS A MODEL FOR PLANNING AND CONTROLLING ETO DESIGN PROJECTS

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ABSTRACT

In the modern engineering environment design projects have become increasingly complex; this calls for an updated perspective on how to plan and coordinate design projects. This paper describes the identified premise that will lay the foundation of the development of a model for planning and controlling such projects. The premise includes principles, requirements, and methods derived from theories around subjects, such as, production theory, lean and agile. The distinctiveness of the design process has been central when setting the premise for the model.

KEYWORDS

Design, coordination, control, complexity, ETO, maturity levels, Agile, LPS

INTRODUCTION

Design as a phenomenon is characterized by iterations, puzzle making and problem solving. Moum (2008) applies the metaphor playing jazz and baking bread to illustrate that design is comprised of both reflective (Ellegård et al. 1992) and linear elements. Learning and gradual maturation characterizes, in particular, the “jazz” part of the design process (Kalsaas and Moum 2016). Design can also be understood as a wicked problem. Rittel and Webber (1973) characterize a wicked problem to have no stopping rule, and solutions to wicked problems are not true-or-false, but good or bad. A wicked problem is made up of complex interdependencies. The effort to solve one aspect of a wicked problem may reveal or create other problems. The complex interdependencies can be described as reciprocal (Thompson 1967) between different disciplines in design.

Previous literature has covered several aspects regarding lean design and engineering projects. Kuprenas (1998) provides good insight in how an engineering organization can be reorganized to become lean. Performance measure, which will be an important aspect of a design management model, has been covered in several previous papers, such as in Serpell and Alarcon (1996). There has also been done work on specific challenges such as partnering by Howell et al. (1996), and design and documentation deficiencies by Tilley et al. (1997). Ballard and Koskela (1998) state that “*one major reason for the poor level of design management has been the*

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lack of solid conceptual foundation." They conceptualize design into the conversion, flow, and value generation view. Freire and Alarcón (2002) somewhat criticize this approach, and adds several tools to enable lean design management. In this paper the intent is to take this idea one step forward, and move towards a model for a specific type of design projects, in this case ETO projects. This model can then be tested, and an attempt at creating a generic model can be realized.

The Last Planner System (LPS) (Ballard 2000) was designed to handle both construction and design. However, Ballard did not test the system in the design phase of construction in his doctoral thesis. Several attempts has been made to apply LPS in engineering for some time, but it has proven challenging since the associated tasks, to a substantial extent, are prone to significant changes. Furthermore, it has been demonstrated that the learning aspects and the gradual maturing of design objects are challenging to handle[4]. It seems like there is an emerging realization that LPS needs to be further developed or complemented with other methods to handle such challenges. This paper presents the preliminary development of a new execution model for design and engineering which addresses the aforementioned issues, this is our primary objective. We believe that this can be accomplished by building on some of the principles from LPS (Ballard 2000). Koskela et al. (1997) conclude that LPS can be used in design management, which further strengthen that this is achievable.

The topic of our research is related to the development of a construct for execution and control of design projects, grounded in the dynamics of design. For this purpose we apply constructive research (Lukka 2003). The relevance is tied to the benefits of being able to manage design project in a predictable manner, while providing customer value such as build-ability and laying the foundations for proper operations (end use).

We apply a case from the oil and gas sector for our initial development of the model. The case company designs and builds mechanical constructions for offshore drilling. The constructions are the foundation for machines and equipment used when drilling for oil and gas. The case company usually acts as a supplier to companies that deliver turn-key drilling modules to the oil companies. The equipment supplier provides our case company with system engineering. The engineering phases in the case company are defined as: layout, design, detail design and drawing. We limit the case to study engineering-to-order (ETO) projects, which means the case company is also responsible for fabrication. Engineering-Procurement-Construction (EPC) contracts are utilized.

The following section highlights the principles and requirements of the construct. Thereafter we address methods and techniques we want to extract ideas and elements from. Finally we address verification issues to somewhat validate the construct before we conclude and address some further development issues.

PRINCIPLES AND REQUIREMENTS

Principles lay the foundation for the Design Execution model (DE-model), and steer the direction in which methods and techniques should be included. The model should be based on the dynamic of the design processes, thus it needs to take some of the characteristics of design into account. The phenomenon of design is characterized by

[4]Based on unsystematic empirical data/experience

a balance of creativity and rationality (Bonnier et al. 2015). The process of envisioning and developing can be described as creative, iterative and open-ended. Engineering design involves a systematic and intelligent generation of design concepts in conformance to specifications needed to realize these concepts (Dym et al. 2005). Ballard (1999) argues that design requirements and their respective solutions evolve as the process progresses, which is what Thompson (1967) depicts as reciprocal dependencies: relationships where output from one activity establish the next. According to Kalsaas and Sacks (2011) a better understanding of the different types of dependencies among management will result in improved decision making in regards to how work is organized, this could be accomplished either by avoiding the most complex dependencies or by meeting them with awareness. This relationship among activities needs to be taken into account in the DE-model. Thus, it is required that the model focus on the interfaces which exists among these activities, in order to handle the reciprocal interdependencies.

Another important aspect of design is the learning and maturing process that occurs throughout the process. Kalsaas (2011) conceives design as a learning process where one develops and optimizes a solution. Consequently, the DE- model must take the aspect of learning into account. This can e.g. be done by addressing learning and maturing in selective milestones in the project. For example, a retrospective meeting,which will be in line with the last principle of the Agile Manifesto (Beck et al. 2001), after each milestone where the team reflects and adjusts its behaviour, could enhance the learning process.

The design process can be considered as a process which produces information, as stated by Bauch (2004)*"Product development [...] can be understood as some kind of information creation factory."* Thus, the principles of production should be highly relevant in the context of developing an effective DE-model.Koskela (1999) proposes five principles for a production control system: (1) Assignments should be sound regarding their prerequisites, (2) the realization of assignments is measured and monitored, (3) causes for non-realization are investigated, (4) maintaining a buffer of tasks, (5) in lookahead planning, prerequisites of upcoming assignments are actively made ready. Maybe except for the buffer-aspect, there is little reason to believe that these principles do not hold true in the context of design, and the DE-model should take the principles into account.

The design process plays a crucial role throughout the product life-cycle, and affects both the manufacturing and operational phases. It is essential that the product design is precise at the earliest stages of development. The design phase typically accounts for approximately 5% of a products total cost, but it affirms to 75% of a product's total manufacturing cost, which indicates the importance of good design (Verma and Dhayagude 2009). Failure to involve manufacturing early has the capacity to create waste, and will likely affect these affirming costs greatly (Bonnier and Ose 2015). Consequently, the principles of the DE-model should address this issue. In the context of concurrent engineering, Smith (1997) summarize the fundamentals as: *"the increased role of manufacturing process design in product design decisions, the formation of cross-functional teams to accomplish the development process, a focus on the customer during the development process, and the use of lead time as a source of competitive advantage."* Obviously, all products have constraints imposed by the manufacturing process, which will affect the details of the product design. If such constraints are addressed early in the process, an opportunity to reduce manufacturing costs and improve product quality emerges (Smith 1997). Thus, in accordance with the fundamentals of concurrent engineering, one of the principles of the DE-model should be to involve manufacturing and the customer early in the design process.

Ballard (2000) introduced the terms negative and positive iterations, where positive iterations are the processes that create value. Negative iterations are connected to what is perceived as rework in the design process, and what iterations that can be removed without decreasing the level of value creation. However, it can be a challenging effort to separate these since the path to the desired result is commonly unknown. This implies that the DE-model should encourage positive iterations. If the various disciplines move forward in an agreed phase, the amount of negative iterations and waste should diminish. This can be seen in relation to takt time planning. Takt time is explained by Frandson et al. (2015) as: *"the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)."* This should also hold true for the production of information in design. Thus, a principle of the DE-model should be to enable takt, in an attempt to reduce waste and negative iterations.If it is not possible to enable takt, the various disciplines should at least move forward in an agreed phase speed.

Toyota has grown to become the global market leader in the automotive industry, perhaps only challenged by Volkswagen (Deutsche Welle 2015). The growth and market share of Toyota certainly sparks the interest to study the company's practices, in an attempt to identify its reasons for success. Singer et al. (2009) write that *"Many believe that Toyota's design process is one of the major accomplishments that have enabled them to be so successful."* The paradox in their design process, compared to other car manufacturers, is that Toyota severely delays critical design decisions, while still having a time to market that is shorter than their competition. Singer et al. (2009) explain that the reason for delaying decisions is connected to costs, knowledge, and influence.While Toyota has shared several details of their manufacturing practices, they have perhaps not been quite so loquacious and eloquent about their design process. Some clues to Toyotas design process can be found in the works of Morgan and Liker (2006). They identify 13 Lean Product Development (LPD) system model principles, which make up the Toyota DNA. Toyota DNA is what Toyota calls its process and culture, in an attempt to explain the difference between their company and others (Singer et al. 2009). Inspired by these principles, some principles of the DE-model can be suggested: establish a working definition of value in order to reduce waste, standardize where possible in order to reduce variation, and using visual management.

Set-based concurrent engineering (SBCE) can be identified as one of the reasons for Toyota's successful design process. The typical process of SBCE starts with developing sets of design for a given design problem. Instead of striving to identify one solution, several design options are developed, and gradually eliminated, until only one remains. A complex design problem requires the involvement of several engineers or functional groups. Thus, SBCE advocate that sets of solutions to the problem should be developed by these groups from their perspective. Later, these groups interact with each other by comparing the sets. They look for the regions that overlap in their design alternatives; furthermore these regions are narrowed in parallel to the point where one solution is left. One benefit of this approach is that the knowledge possessed by highly specialized engineering functions, that is typically difficult to share, is re-combined from the independent solutions into the integrated final solution (Bernstein 1998). The benefits of this approach to design are that SBCE provides a mechanism that enables managers and engineers to delay decisions. Even while they still are developing a product. Bernstein (1998) summarizes the benefits of SBCE as*: "The effects of SBCE, therefore, are to delay the commitment of costs and to increase management influence late in the development process."* However, implementing a SBCE-environment might be too radical a change for most companies. Still, the benefits of SBCE can be somewhat preserved as a principle of the DE-model: delaying commitments of costs when the commitment is not required as a prerequisite for downstream processes. In other words, the principle can be that engineering information is pulled from downstream processes when possible.

SCRUM

Agile Methods are a response to the need to handle the rapid changing requirements in the software development industry (Cohen et al. 2004). Although these methods and practices vary, they share some common principles and practices, such as incremental, iterative development cycles in order to complete projects (Abbas et al. 2008).

The term Scrum has its origins from rugby: going the distance as a unit passing the ball back and forth. The analogy depicts the continuous interaction of a cross-functional team whose members work together from start to finish, towards a common goal (Takeuchi and Nonaka 1986). The methodology shares some of the main practices of the other Agile Methods, such as incremental and iterative development cycles. The customer requirements act as a driver for the iterations. The cyclic development process continues until the project is no longer funded (Schwaber 2004). At the beginning of each iteration the development team reviews what has to be done. These iterations are termed as Sprints, and typically last for 2-4 weeks (Hoda et al. 2008). The team determines what needs to be done and selects the most appropriate way to implement functionality. This creative process is the core of the Scrum's productivity. The roles that are typically involved in this process are Scrum Master, Product Owner, and of course the development team. All managerial responsibilities are divided among these roles (Schwaber 2004). The Product Owner represents the customer's interest and is responsible for preserving the right business perspective (Hoda et al. 2008). The Product Backlog is the list of requirements which the Product Owner uses to ensure that the most valuable functionality is developed first and then built upon. The elements in the Product Backlog are prioritized in order to aid the development team when deciding which functionality to work on in the upcoming Sprint. The development team is a self-organized unit, and is comprised of personnel which are cross-functional. Typically the development team consists of 5-9 members. The team is responsible for incrementally transforming the Product Backlog items into functionality through each Sprint (Schwaber 2004). The Scrum Master is a member of the development team and acts as a facilitator for the Scrum process and is responsible for removing any impediments that might obstruct the development team in their daily chores. In addition, the Scrum Master is also accountable for teaching Scrum to everyone involved in the project (Sutherland and Schwaber 2011). These three aforementioned roles are the ones that have committed to the project and are the ones responsible and with authority. Others might indeed have an interest in the project, but they are not authorized to interfere with the development process (Schwaber 2004).

The Sprint Planning meeting initiates each Sprint. This is when the Product Owner and the development team collaborate about determining what functionality to develop and implement during the upcoming Sprint. Typically, the top prioritized items from the Product Backlog are chosen (Schwaber 2004). The selected items combined are the elements which comprises the Sprint Backlog, which refers to the tasks needed in order to implement functionality in the impending Sprint (Hoda et al. 2008). Every morning the team gets together for a 15-minutes meeting called the Daily Scrum. The objective of the Daily Scrum is to synchronize the work of all team members daily and to schedule any meetings needed to ensure progress. A Sprint Review meeting is held when a Sprint comes to an end. The development team presents what has been achieved during the Sprint to the Product Owner for review. Subsequently a Sprint Retrospective meeting is held, which purpose is to make the development process more effective and enjoyable for the following Sprint (Schwaber 2004). Furthermore, the Sprint Retrospective provides the team an opportunity to learn from the past and adjust its course accordingly (Landaeta et al. 2011). Adaptation and learning are crucial aspects of delivering value to the customer according to the agile philosophy(Highsmith 2009). Together, the four aforementioned events establish the empirical assessment and adaptation practices of Scrum (Schwaber 2004).

Scrum appears to be based on the same paradigm as LPS when it comes to collaboration and is based on a relational approach, not transactional. We have made the proposition that elements from Scrum has the potential to enhance LPS's applicability to engineering. In particular the challenges associated with handling significant changes could be mitigated by applying Sprints. Events such as Sprint Planning and Sprint Review meetings might ensure close and continuous collaboration between the team and the customer, and could act as a forum to handle substantial changes. Minor issues may well be handled by the autonomous teams in the Daily Scrum meetings. The challenges related to learning could be handled by applying Sprint Retrospectives to supplement the Sprint Reviews. This would ensure that both the product and the work process itself are continually evaluated. We find these ideas of incremental problem solution and iteration to be promising for handling and controlling the wicked challenge inherited in design.

THE EXECUTION DESIGN MODEL

The conceived model is constructed based on ETO-projects and EPC-contracts. The point of departure is from the point in time where the contract is signed. By that time the project team got an idea of the construction method and which work the company will outsource, which follows from the tender process. From the tender process the team is moreover to some extent aware of risks, complexity and hours needed in the project. The model is constructed in five steps:

1. Master plan Engineering (milestone plan)
2. Phase plan (reversed scheduling based on functional milestones)

3. Flexible takt plan made up of design work packages and Sprints (functional engineering packages managed by self-organized teams)
4. Manual work scheduling internal to each Sprint
5. Sprint reviews (root causes to deviation, learning – continuous improvement)

The model is based on that a design project is divided into sections / control areas. The division is often related to the needs of fabrication. The milestone plan is the key element for keeping the project on time. If necessary, extra resources are used to successfully achieve each milestone. The milestones used are often generic within a business, based on the methods and logic that repeats itself, even though projects have many unique properties. However, lead times and time determination of milestones differs from time to time, such as different sectioning.

The stage plan prepares a sequence of activities that must be performed to reach each milestone for each section / control area. Some milestones are global, while others are connected to the section / control area. Iterations, incremental design, and gradual maturing, are handled in work packages and Sprints. Each work package consists of one or more Sprints. Each Sprint is handled by autonomous multidisciplinary groups.

In the takt plan Sprints, order, and the amount of time teams have at their disposal, are identified. The takt plan is balanced against the resource capacity. The autonomous groups create their own flexible work schedules. A relevant critical question is if the takt principle is too rigid for design work. This is easily imaginable at first glance, but for any method we need a predictable progress, which also holds true for design. The idea is to build flexibility into the Sprints for the iterations and the interactions where this is considered necessary. Here the self-organized teams play a key role, and they must deliver, but they decide how they solve the tasks at hand, and retain responsibility for the detailed planning.

Sprint reviews are an important meeting, in order to control quality against criteria and to apply systematic learning, where experiences and causes of any challenges are shared throughout the project.

CONCLUSION

Within all organizations, a standardized method of executing complex projects is essential for a valuable outcome from projects. Such a model is defined as a stepwise definition of what do by whom to execute design projects, based on an execution philosophy. The aim is to speed up design work and to increase the reliability and quality, which require a model that is responsive to the frequent changes, creativity, iterations, gradual maturity, learning and the wicked character of design projects. The benefits are expected to be reduction in cost and waste and increased reliability in term of progress. The relevance is moreover related the great importance of design for value regarding build-ability and the operation phase for end-users.

The model presented in this paper is developed in an attempt to tackle the requirements by implementing different theories and planning methods. While the presented model might require further development, it is in its current state close to ready to be implemented. Thus, the constructed model will be verified and tested in real design projects at the case company.

FUTURE RESEARCH

A more elaborate version of the model will be tested in an ETO project context to verify its applicability. We aim to develop and apply the model, or at least elements from it, on an upcoming project at the case company. It might also be beneficial to look further into the Nexus framework with regards to coordinating multiple Scrum teams.

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