LITERATURE REVIEW ON PLANNING DESIGN AND ENGINEERING ACTIVITIES IN SHIPBUILDING

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ABSTRACT

Planning, scheduling, controlling and measuring design and engineering activities is challenged nowadays not only by the strong competition, but also by the technology and the way projects are organized. The project organization challenges the planning process through its variety of people, organizations and cultures participating along the whole building project. Concurrent engineering is a building method dependent on a dynamic planning process that integrates and coordinates all the entities involved in the project. 3D modeling is a tool that necessitates more specialized engineers and a more collaborative way of engineering a project. It seems that today's planning systems fail to take into consideration these challenges. This literature review is an attempt to find if and how the fields of project management and lean construction deal with planning and measuring design/engineering activities in a concurrent engineering process that is globally dispersed both on engineering and on production part of a project.

KEYWORDS

Project Planning; Lean Construction; Last Planner System, Project Management

INTRODUCTION

Planning occurs on several levels and in many places within an organization: from planning a new acquisition at the strategic level, to "*assigning available resources at an engineering management level, to the level of individual designers who may wish to plan their own activities*" (Eckert and Clarkson 2010). In fact, all business activities need to be planned and all these plans are usually connected in an intricate and often unpredictable way (Eckert and Clarkson 2010). In managing and controlling projects, planning is an important factor that can contribute to both success and failure of meeting their objectives. In fact, the United States Government Accountability Office examined 413 projects that failed to achieve their goals, and 79% of the causes were due to poor planning, 15% were poorly performed and 6% were both. Within project management literature, Kerzner (2013b) identifies numerous root causes for project failure and among these several are planning related: "*Poor overall planning, lack of re-planning on a regular basis, plans based on insufficient data, no systematization of planning process, and planning is performed by a planning group*".

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The "Guide to Lean Enablers for Managing Engineering Programs" published by the Joint MIT [1] -PMI [2] -INCOSE [3] Community of practice on Lean in Program Management combines the three knowledge domains of operation research, systems engineering and project management in order to "*distill and integrate the best ideas and practices from those and address the today's challenges*" (Oehmen et al. 2012). Among the ten challenge themes in engineering programs identified within the guide, two of these are directly connected to project/program planning and controlling processes: *"Insufficient planning; and improper metrics*".

The Lean Construction literature emphasizes the importance of good and practical planning systems that involve the right people and processes. The best example here is Last Planner System created with the aim of improving the planning process in a construction project. Although most of the practitioners and academics agree that planning is undeniably essential to assure project success, the project planning in many organizations within different industries "*leaves a lot to be desired* "(De Reyck 2010).

One of the industries focusing on improving the planning process is the shipbuilding industry in Norway. This paper is part of a PhD research, developed in collaboration with Norwegian Research Council, Vard Group AS, SINTEF, Molde University College and Molde Research Institute, that analyzes the planning processes for design and engineering activities within shipbuilding. The rest of the paper is organized as follows: first a presentation of shipbuilding in Norway; then the methodology approached for the literature review, followed by the preliminary findings and a conclusion part.

SHIPBUILDING IN NORWAY

Shipbuilding in Norway has, during the last two decades, become a more and more geographically dispersed and multicultural industry where most of the shipyards build their hulls outside Norway in an attempt to remain competitive in an increasingly demanding market. Building hulls in other countries has proved to be a challenge from several perspectives such as: Planning the whole project, engineering the project, logistical issues, procurement, strategy, cultural differences and so on.

Yet, one important characteristic of Norwegian shipbuilding industry is its flexibility. This gives customers the possibility to decide many features of the vessel during the building process which is characteristic to the Engineering-to-Order (ETO) approach. Maintaining this flexibility while finding feasible solutions to the challenges mentioned above has become a complex process in which the industry needs to analyze and improve every practice used along the project execution.

Most of the shipyards in Norway are approximately matrix organized where each vessel to be built is a project managed by a project management team with support from the line organization. The planning process of these projects was until recently mainly focused on the production part of a project without integrating design or engineering activities. But, a stronger competition on shorter building period, a more

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[2] Project Management Institute
[3] International Council for Systems Engineering

geographically dispersed organization, the adoption of 3D modeling as a working tool in a concurrent building process where Engineering, Procurement and Construction (EPC) is almost performed in parallel, and increasing complexity of the ship, challenged the need to integrate design and engineering activities within the planning process. Figure 1 presents both the sequential and the concurrent approaches used within shipbuilding industry, as well as some of the advantages of using a concurrent building method. The sequential building approach is simple and follows a well-established logical way of thinking: first design and engineer the project, then buy the equipment and the materials, and then build the vessel. This is typically the way shipyards work in the Far East. Through the concurrent approach, the building period is reduced by producing parts of the vessel as soon as they are finished on the drawing/modeling phase. However, a successful concurrent approach is dependent on a dynamic planning process, excellent coordination and a good communication system between entities involved within the project (Emblemsvåg 2012). In fact, Pieroni and Naviero (2006), and Andristos and Perez-Prat (2000) claim that due to the strong competition on shorter delivery period in the shipbuilding industry, this industry seems to be more interested in implementing concurrent engineering (CE).

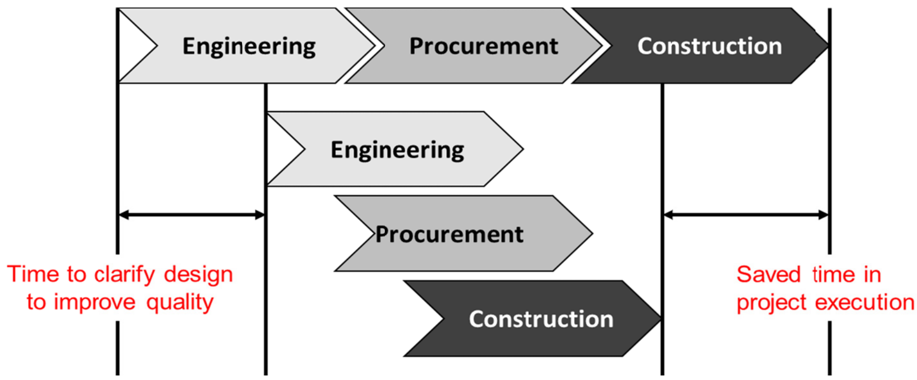

Figure 1: Sequential versus Concurrent EPC (Emblemsvåg 2012)

One of the shipyards in Vard Group in Norway, implemented a new planning method called Lean Project Planning (a tool based on the marriage between Last Planner System and Earned Value Management) that proved to be a success for the Norwegian production department (Emblemsvåg 2014a). However, this planning tool was implemented only at the production department. Challenges of using this approach in the design and engineering processes includes: 1) engineers have historically not been involved in the planning process and have less training in defining and measuring their work clearly or work according to a plan; 2) engineering assignments can be iterative and hence hard to measure progress with respect to production of drawings as traditional project planning suggest and 3) engineering assignments are harder to define precisely due to 3D modeling and the inherent iterative nature of engineering (Emblemsvåg 2014b).

For example, in a recent discussion with some technical coordinators on some on-going projects they estimate that the Percent Plan Complete (PPC), the percentage of activities completed as planned, for design/engineering activities was between 50-60% compared with production where the PPC was over 90%. Given the performance problems of engineering projects in general it is evident that research is needed for establishing an approach that can improve the performance of engineering projects.

This leads us to the main focus of this paper which is to identify what is the current best practice in planning of design and engineering activities including 3D modeling tools, performed within a concurrent EPC environment. An additional challenge is that design/engineering and production value chains are geographically dispersed and multicultural. In order to understand the challenges better, a short description of the design and engineering processes for the case study is needed.

DESIGN AND ENGINEERING PROCESS– CASE DESCRIPTION

The design and engineering process within a shipbuilding project is divided through a somehow unclear delimitation particularly in engineering. The Design department, usually a separated group inside the company, is the one involved within the project from the beginning and ends with an approved class package from the Class Society. In this process they also create a basic 3D model that fit customer's main ideas about the future vessel and is used during the negotiation phase. At the end of negotiation phase, a General Agreement (GA) drawing together with a specification document (written in collaboration between customer, Design department and Procurement) become an important part of the contract. The shipyard selects a Project Manager and the project organization that will follow the whole project and complete the engineering process culminating in detailed production drawings in the thousands. The assigned Technical Coordinator (TC) is now in charge of the rest of the design- and engineering phase of the project. His/her main task is to coordinate the engineers allocated to the project and the flow of information both within the organization and towards procurement, production, suppliers and the customer as well as Class Society and authorities. Most of the engineering activities are either related to coordination or to 3D modeling. An interesting aspect of 3D modeling tools is that by offering the possibility to see more details within each drawing, it also makes the work more laborious due to the fact that each small detail must be created and introduced into the model. Another issue regarding 3D modeling is that the modeling process now involves more specialized engineers. Planning, controlling and measuring the progress of all these activities and all resources therefore become a more complex process than presupposed by traditional planning approaches.

The planning phase of the whole project is by now containing a Master Plan including a Milestones Plan and the activities allocated to each of the major entities involved within the project: Design department; Engineering; Basic Design; Hull yard; Outfitting yard; Piping; Electro; HVAC (Heating, Ventilation and Air Conditioning); and Accommodation. These entities are involved both in the 3D modeling and production phases and are responsible for planning their own activities according to the Master Plan. The detail engineering phase coordinated by the TC located at the outfitting yard is planned based on a drawings list containing several hundred items to be allocated per entity involved within the project. Due to a lack of necessary resources, many of the 3D modeling activities are subcontracted to different companies located outside shipyard premises. Most of these subcontractors create their own internal project organization to keep control over progress and deliveries. But, even though the design and engineering activities are split between so many organizations, the tasks of each discipline are interdependent in terms of contents, time and technical solutions (Kerosuo et al. 2012). This creates significant coordination and planning issues.

Analysing the description of the practices used by the shipyards to manage their projects one can notice that even though each shipyard is approximately matrix organized, their design and engineering activities are managed more like network organizations with the Project Manager (PM) and Technical Coordinator as hub. This is an important aspect for managing the design and engineering work.

A network organization as defined by (Gray and Larson 2006, Morris and Pinto 2004) is an "*alliance of several organizations for the purpose of creating products and services for the customers*". Within such projects a core company coordinates the network while providing few core competencies like product development or procurement. The advantages of this type of organization are: 1) Cost reduction; 2) High level of expertize by hiring firms with know-how (the company can focus on developing its core competencies); 3) Flexibility by being able to combine own resources with talents of other companies. Among the disadvantages of such organization are: 1) Coordination breakdowns due to challenges in adjusting mutual objectives or accepting close collaboration; 2) Loss of control due to the fact that core company do not have direct authority over the hired team; 3) Conflicts due to different perspectives on value, priorities, and culture. Project management literature recommends choosing the project organization according to the project's needs (Morris and Pinto 2004) and that of course, influences the project planning process. Within shipbuilding projects network organized projects seem to be the norm and the advantages and disadvantages listed above are experienced by practitioners.

Figure 2 illustrates both internal (daughter company with the group) and external entities involved within a shipbuilding project from the perspective of a Technical Coordinator. Most of the entities have their own project organization behind them and that is an important aspect on the flow of communication. Another important aspect here is that without a standardized planning process the planning process become dependent on the skills and personal abilities of every Technical Coordinator.

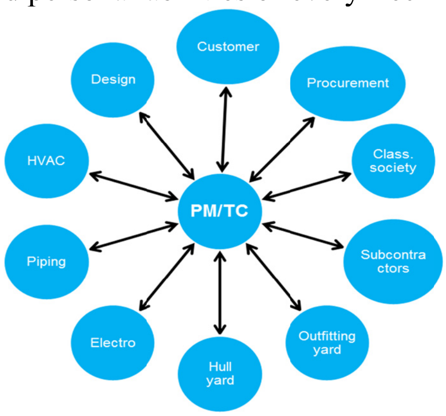

Figure 2: Network organized projects

This type of project organization is not a typical lean organization and it is the task of this PhD research to find out if it is feasible to implement lean concepts in such complex organization structure.

Looking at all the factors influencing the planning process of engineering activities, it becomes clear that this is a challenging process. How to manage such activities? How to measure the physical progress correctly so that we can judge whether the project is on schedule, behind the schedule, or ahead the schedule? How to identify root causes of deviations so that solution can be found quickly and the project can return back on track (Emblemsvåg 2014b)? This paper consequently, focuses on identifying the state-of-the-art within planning of design and engineering activities. The methodology approached for this research is described next.

LITERATURE REVIEW

The literature review was based on internet search and through Molde University College a number of databases were searched, such as ProQuest; Science Direct; Planning Planet; Google Scholars; Project Management Institute, Lean Advancement Initiative; International Council on Systems Engineering, and Lean Construction Institute. The subsequent phase of the research was to find literature that is specialized in project planning, scheduling, measuring metrics for engineering activities in order to find out how this is done in domains like: shipbuilding, construction, IT, systems engineering, and project management.

One of the most useful documents found is "The Guide to Lean Enablers for Managing Engineering Programs" published as a joint collaboration between Massachusetts Institute of Technology, International Council for Systems Engineering and Project Management Institute (Oehmen et al. 2012). The guide actually combines known best practices from lean literature, project management and systems engineering with input from an extensive community of practitioners. The guide identifies and analyse ten major challenge themes in managing engineering programs and their possible solutions based on practices from lean thinking, project management and systems engineering. The references provided throughout this guide are also useful theoretical background for this research. Broadly speaking, the most useful literature is found in Project Management literature and Lean Construction literature as presented in the next two sections.

PROJECT MANAGEMENT LITERATURE

Most of the books on project management treat planning as an important tool for managers who want to have a good control of the projects they are in charge of. A 30% increasing in the number of Project Management Certifications and the growing number of organization using planning software (e.g. Microsoft reports over 20 million users worldwide) (De Reyck 2010) are supporting the statement above. However, most of the software used for project planning do approach the process using a linear, water-fall method based on deliverables (Kerzner 2013a), but are unable to handle documentation and iterations that are so specific to design and engineering activities. In a recent paper Liao et al. (2012), state the fact that engineering productivity is less understood than construction labour productivity, even though the cost of engineering has increased up to 20% of total costs of a project.

Project Management Body of Knowledge book (PMBOK) (PMI 2013a) mentions concurrent process only as a short notice on overlapping relationships. Concepts like design, engineering, CE, network organized projects are not discussed within this edition of the book. The book is more like a collection of definitions and recommendations of common used project terms to be implemented in different phases of a project. The planning process is based on a linear strategy, a traditional approach that "*consists of dependent, sequential phases that are executed with no loop feedbacks*" (Fernandez and Fernandez 2009). Among the disadvantage of this approach are: 1) plans do not accommodate change very well; 2) must follow a defined set of processes; 3) requires detailed plans; 4) is not focused on customer value as much as delivering against the plan (Fernandez and Fernandez 2009). The comparison of these characteristics with the needs identified in shipbuilding earlier in this paper indicates a clear mismatch. PMBOK needs an update that can answer to the challenges of more globally dispersed projects managed to fit a concurrent process. Planning and measuring design and engineering activities should be a topic included within PMBOK.

On the other hand, Kerzner (2013a), describes CE as a method of reaching the market faster, but he caution against costly risks connected to using this method. He states that the best way of minimizing risks within project management is for the organization to plan better. Nevertheless, the planning methodology described in his book does not treat the subject of planning for CE processes. However, the author defines virtual teams and their increasing influence on the way projects are managed nowadays. The definition is close to a network organized project and the author identified several types of virtual teams, their characteristics and challenges from the technical and cultural perspectives (Kerzner 2013a). This book fails also to see the needs for a better planning adapted to design and engineering activities.

A more comprehensive book on project management is actually a collection of works of many authors coordinated by Morris and Pinto (2004). This book introduces the network organized projects, its advantages and disadvantages. A whole chapter is dedicated to CE, its advantages and its challenges, while describing different steps on implementing such process. However, here too the planning process is based on the same linear methods used within project management literature, without considering the challenges of planning design and engineering with their iterative nature.

Gray and Larson (2006), approach in their book a more scholastic perspective on the managerial process within project management. They describe the advantages and disadvantages of network organization, but the concept of CE is treated at a superficial level. Being focused more on the manager's work, the book assumes planning for design and engineering activities within the same linear process as PMBOK. Other books treating planning for project management such as (Lewis 2011, Lock 2003, Meredith 1999, Nicholas and Steyn 2012) recommend methods based on the same type of linear solutions, without considering a planning process for CE.

The preliminary results of this research show that project management literature does not take into consideration the evolution of design and engineering tools and the way these challenge the planning processes. Design and engineering activities are considered and planned the same sequential way as production activities. Neither the planning process nor the scheduling does approach the challenges of planning and scheduling concurrent engineering activities. The project management literature treat design and engineering as activities that can be planned and measured with metrics like: hours per drawing, hours per engineered element, and hours per engineered quantity (Liao et al. 2012). In other words, engineering activities are measured on deliverables. But the design and engineering activities consist of more than that and a good example is that making a drawing today can take 5 minutes whereas the engineering design process prior to delivery can take days, weeks or even months in some cases (Emblemsvåg 2014b). The reason for this is the introduction of the 3D modeling which the traditional project management literature ignores.

The traditional project management methods of measuring progress fit the old ways of engineering a project where determining the duration of making a drawing was done manually by the engineer working on it. Nowadays, the 3D model is produced through collaboration between different specialized engineers who work almost simultaneously within the model. To measure physical progress in the old ways becomes impossible because drawings are merely snapshots from the 3D model and take just minutes to make. This is the primary reason for focusing on 3D modeling in this research.

Within shipbuilding, an interesting aspect to be remarked is that many of the Norwegian shipyards are approximately matrix organizations, but each project becomes a network organized endeavour. Both linear and matrix organized projects implies that team members are co-located on a proximate zone, but this is one of the main challenges within shipbuilding where engineers are globally dispersed and the production process is also divided in several locations. Due to such factors, the literature on shipbuilding studies network organized projects, but under names like: Collaborative Engineering Communities, Multi-Organizational projects; and Project Network (Gronau and Kern 2004, Leufkens and Noorderhaven 2011, Mello and Strandhagen 2011, Wikstrõm et al. 2010). This confirms that the traditional project management is adapting quite slowly to the challenges within the practice and needs an update.

LEAN CONSTRUCTION LITERATURE

Ever since 90s, lean construction community recognized the need for a change in the way traditional project management plan and measure activities in a project. One of the best examples is the invention of Last Planner System (LPS), a planning tool intended "*to provide the component missing from the traditional project management kit*"(Ballard and Howell 2003). The role of LPS is to increase planning reliability by decreasing workflow variability, through recognizing and removing activity constraints, identifying root causes for non-completion of plans and monitoring its improvement by means of PPC (Olano, Alarcon, and Razuri 2009).

There is a high amount of papers on project planning for both design and production activities on Lean Construction Institute internet page. One of the first papers published on this subject was written by Koskela et., al.(1997) and describes the situation for design departments where chaos and improvization are replacing planning and control. The design management is still a very disscused topic within the field of lean construction. Many of the papers agree on the importance of planning for design activities (Ballard 2000a, Freire and Alarcon 2002, Koskela, Ballard, and Tanhuapaa 1997, Rosas 2013, Wesz, Formoso, and Tzotzopoulos 2013) while others are presenting different cases of applying the concept of design management (Kerosuo et al. 2012, Tzortzopoulos et al. 2005). However, the topic on CE and its challenges for planning and managing design activities seems to not be approached by lean construction literature either. Letens, Farris, and Van Aken (2011), found out that the development of CE as a building technique is not as advanced as it might seem. They present a report showing that although 75% of aerospace companies and 62% of industry as a whole report on using CE, only 16% confirmed that they had been able to fully implement CE across the company. Some of the reasons are laying in the "*fragmented approach to CE implementation that focuses on improving integration, collaboration, and process compression with a strong bias toward technology, while neglecting value identification and product effectiveness*" (Letens, Farris, and Van Aken 2011). It seems like construction industry is probably slower than shipbuilding in adapting CE as a working process.

Sacks and Barak (2005), study the advantages of using 3D modeling within construction and they recognize the challenges of measuring these activities. They propose a simple method based on constructed facilities rather than document counts. This method is difficult to apply in a building process that is globally dispersed.

Some researchers within lean construction identify the effect of independent design and engineering teams on the flow of information which is losing its flow due to the numerous links within the process (Tribelsky and Sacks 2010). A good example here is a subcontractor waiting for technical information (footprint) from the Technical Coordinator who has ordered that to the Procurement department who ordered that to the supplier. Such interrupted flow of information is also affecting the implementation of CE which is highly dependent on a good communication between entities involved in a project.

Lean construction literature identifies challenging design characteristics and Male (2007), summarizes three of them:1) requirements are often not clearly specified and interpretation of problems are subjective; 2) the process is multidimensional, highly collaborative, and represents the interests of many stakeholders; and 3) problems become gradually clearer as solutions advance. Most of the solutions proposed for dealing with these challenges are based on LPS (Ballard and Howell 2003, Hamzeh, Ballard, and Tommelein 2009, Letens, Farris, and Van Aken 2011, Orihuela, Orihuela, and Ulloa 2011, Reifi, Emmit, and Ruikar 2013, Tilley 2005). However, Kalsaas (2013), and Emblemsvåg (2014a), agreed in that LPS is not able to handle advanced engineering design work and needs a better instrument to measure physical progress for such activities. Solutions proposed by these two authors are inspired form offshore drilling construction and shipbuilding respectively, and propose some interesting improvements to the LPS. Kalsaas (2013), proposes an Integrated Project Engineering Delivery System while Emblemsvåg (2014a) introduces a new approach called Lean Project Planning. These attempts to improve LPS prove that this tool needs some adjustments in order to respond in a better way to challenges like CE, 3D modeling and globally dispersed design/engineering teams. However, so far, no one has provided a satisfactory framework for planning of design and engineering activities.

PRELIMINARY FINDINGS AND CLOSURE

Planning, scheduling and controlling design/engineering activities for 3D modeling activities in a CE process with a network organized project is a scarce subject to find within project management and lean construction literature. One of the reasons for this can be the fact that CE is not yet fully developed and practitioners are trying to figure out some ways to improve this approach. This is probably one of the reasons explaining why this subject is so little approached by project management literature.

Furthermore, both project management and lean construction literature provide very few studies on 3D modelling and its effect on the planning process. While project management literature assumes that measuring such activities can be done in the same way as before (if it was measured before), lean construction literature acknowledges the need for improving LPS for a better adaptation to technology changes.

The project management literature recommends that the project organizational structure should be designed to fit the project's needs, but the network organized project is recognized only by two sources who do not study the effect such organization has on the planning process. On the other hand, construction industry has been using similar project organization, but the authors found no sources within lean construction literature that study this type of project organization from the planning perspective.

Therefore, the preliminary finding of this paper is that there is a need for a better way for planning, scheduling and controlling design- and engineering activities. However, finding new solutions must take into consideration the challenges brought by 3D modeling, iterative design and engineering activities, CE and the way projects are organized. This is not yet achieved by any as far as we have been able to identify, and this is the most important finding so far.

It should be noted that before we can be conclusive about this finding, we must properly review the field of Systems Engineering although preliminary findings based on (Oehmen et al. 2012) indicate that Systems Engineering also has little to offer with respect to this research.

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