Design of the Building Execution Process in SME Construction Networks

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Abstract: While the implementation of lean management methods in the automotive and aerospace industries is common nowadays, the architecture, engineering and construction (AEC) industry is lagging behind in this development. Up to now, research in construction has been focused on product development, while improvement in organizations and processes has been almost ignored. This paper describes an innovative methodology for planning the building execution process, called Integral Building Execution Planning (IBEP), which is suitable for construction networks composed of small and medium sized enterprises (SMEs). The IBEP approach is part of a new production system in construction with the aim to improve process reliability during the execution phase by integrating actors from implementation into planning. The design methodology IBEP was developed within the research project “build4future”, especially by reengineering two completed projects with their participating key actors.

Keywords: Just in Time, Engineered to Order, Last Planner System, Process Reliability, Small and Medium-Sized Enterprises.

Introduction

The building sector in the Province of Bolzano is one of the key industries for the local economy and one of the largest economic branches in Italy and Europe. However it is composed of SMEs that struggle in price competition with the globalized market. The research project build4future (Matt et al. 2011) was launched to develop an intelligent approach to planning and construction that would eliminate sources of waste in the AEC industry and support local SMEs.

Traditionally, construction project managers have assigned unreliable time schedules without any on site capacity planning which could not be followed by their crews. In a conventional value chain composed of different companies, a delay in work completion by one enterprise affects the downstream activities of the following companies. Since supplier lead times are, for the most part, much greater than the possible accurate foresight regarding work completion, a just in time (JIT) delivery of Engineered to Order components from production to the construction site is not possible.

Recent research studies have shown that a potential cost saving of 30% could be reached by implementing lean processes (Cain 2004). Moreover, from the practical side, a recent survey estimated a potential cost saving of between 11% and 20% by optimizing construction processes (Krause et al. 2012). This confirms the fact that research in construction is needed and that cost savings estimates in research correspond to estimates from practitioners.

This paper is related to the second phase of the b4f project and focuses on the development of a method to optimize the planning process for building execution. For this purpose, two existing buildings were analyzed in order to develop a new production system based on lean concepts from other production sectors.

State of the Art

Owners often commission architectural design and construction separately, so working relations between architects/engineers, contractors and subcontractors vary on a project by project basis (Lincoln and Syed 2011). Due to these changing customer-supplier relationships, the requirements of the involved crafts are unknown among the participants. This often causes high coordination costs in construction projects. Furthermore, in Italy the construction industry has become highly specialized which increases the number of interfaces in a construction project. Every participating trade tries to optimize its own production and installation process without considering their influence on the overall construction process. All AEC clients seek major reductions in the cost of buildings. However, this can be achieved only by an integration of design and construction as seen in other engineering sectors (such as the automobile and manufacturing industries) (Choo et al. 2004).
Planning and management of the design phase requires planners to take into account the iterative nature of the process and the changing needs of the project stakeholders (Choo et al. 2004). The construction sector is characterized by high variability like the changing availability of resources, differing legislative frameworks, a lack of information, unpredictable weather conditions, and so on. Ballard developed the Last Planner® System (LPS) to surpass and optimize the traditional method of construction management during the execution phase (Ballard 2000). He revealed that variability is the major source of waste in construction. The “last planner” is the last in the decision chain of the organization because the output of his/her planning process is not a directive for a lower level planning process but results in production. The last planner only releases workable jobs to the field, as opposed to the traditional practice of pushing assignments onto construction crews in order to meet scheduled dates (Kim et al. 2010).

Traditionally, project management tools address what SHOULD be done to meet a master schedule or Critical Path Method (CPM) schedule, as opposed to verifying what CAN be done. Decision makers often lack the ability to ensure that scheduled work is within a crew’s capability (Lincoln and Syed 2011). Time schedules are usually elaborated without taking into consideration the number of workers needed on site. This means that scheduled work packages are not kept and delays in work completion occur. Moreover, time schedules are not continuously updated and therefore cannot be used as a tool for coordinating the involved actors during a building project. Research in the lean construction community has shown that work flow reliability must be achieved as a prerequisite to managing costs and schedules (Ballard and Howell 1998; Howell 1999).

Koskela (2000) defines a theory as something that explains observed behavior and contributes to the understanding and prediction of future behavior. It has been argued that construction does not have an explicit theory (Koskela 2000; Koskela and Howell 2002). On the other hand, by verifying this statement, one approach was identified which goes partially in the direction of defining a theory. The Metra Potential Method (MPM) was developed in 1958 by the company SEMA and was used for the first time for the construction of nuclear power plants on the Loire (Burghardt 2006). The MPM is a network planning method of the “activity on node” type. In MPM, activities are represented by bars and relations are represented by arrows. In the Extended Metra Potential Method (EMPM), different types of relations (begin-begin, begin-end, end-begin, end-end, percentage) were introduced, as well as negative arrows and cycles. Furthermore variable activity durations suitable for the construction industry were introduced (Kerbosch and Shell 1972). Kerbosch and Shell (1972) stated that they used and tested EMPM in the building industry on different projects concerning planning and project control reaching satisfactory results.

In the manufacturing industry, releasing large batches of work to the shop floor causes several problems. A large volume of work typically occurs over time and it is difficult to monitor the production progress. In addition, this makes responding to changes in customer requirements very complicated (Rother and Shook 2009). The same also applies to the construction sector. Establishing a constant production pace could create a predictable construction flow that would enable quick correction action to be taken in case of unforeseen problems. In Lean Manufacturing, the consistent amount of production instructions released at the pacemaker process and simultaneously the taking away of an equal amount of finished goods is called “paced withdrawal” (Rother and Shook 2009). This consistent increment of work is called “Pitch” and is calculated by multiplying the number of parts a finished goods container holds by the “Takt Time” needed for producing one part (Rother and Shook 2009). This “Pitch” becomes the basic unit of the production schedule for the considered product family.

In construction, unlike the manufacturing industry, the building (product) does not move along a production line but, rather, crafts (workers) move from one construction section to the next. So, the challenge is to synchronize the different crafts within the construction sections to meet the delivery date. Kenley (2005) states that site confusion generally arises from traditional planning systems that provide a plan to the site which cannot be executed. “Construction is the production of a complex, one-of-a-kind product undertaken mainly at the delivery point by a series of repeating but variable activities in multiple locations within a multi-skilled ad-hoc team” (Kenley 2005). Unlike production, construction is organized around discrete activities which are organized in sequence but not by location. To prevent traditional ways of construction disruptions, Kenley suggests a location-based planning system (i.e. a flowline). However, Kenley argues that a flowline requires that construction activities have to be aligned to prevent an extension of the contract duration or a disturbance in the workflow (Kenley 2005).

Yu et al. (2009) designed a production flow and synchronized it to the Takt Time in the home building industry. They argued that applying just lean production tools, like the supermarket-based pull flow, for reaching a reliable working process doesn’t work in construction. Therefore, they proposed a FIFO-lane-based flow system based on the Last
Planner methodology. The mentioned system is based on the so called “Heijunka Box”. The aim is to stabilize and reduce lead time by guaranteeing trade contractor’s working load, using agreed capacity between a home builder and its trade partner on the number of jobs that a subtrade will perform each week (Yu et al. 2009). As a result, Yu showed in the paper that the total construction duration could be reduced by about 41 percent, the waiting time could be reduced by about 11 percent, and the value added ratio could be increased from 17 to 26 percent (Yu et al. 2009). Furthermore, the FIFO-lane based flow was tested with 15 houses that passed through the system which showed that the process variability was significantly reduced.

The PRECISE Production System

An essential prerequisite for success in complex construction projects is that architects and specialist planners have access to information from executing companies and suppliers. In the manufacturing industry this concept is called “frontloading”. However, in the AEC sector, contractual and public procurement law requirements, diverging project objectives, and a lack of process understanding impede an early and interdisciplinary collaboration.

The PRECISE production system was developed as part of the research project b4f in collaboration with 12 South Tyrolean companies. PRECISE is the acronym for Process REliability in Construction for SmEs. This innovative production system integrates different lean management strategies that are suitable for the construction industry in order to achieve process reliability within networks of SMEs. Partnering also plays an important role. Two or more companies collaborate within different projects based on confidence, dedication to common goals, and an understanding of each other’s individual processes, requirements and values. The implementation of lean management principles in construction cannot be effectively done without having the prerequisite of partnering. The PRECISE production system consists of three phases (figure 1):

1) In the Early Interdisciplinary Building Design phase, the project award and the foundation of the project consortium take place as soon as possible. This allows key actors from both planning and execution to evaluate and optimize the building design taking into consideration relevant aspects like: accessibility, constructability, durability, affordability and so on. As a result, an integration of product- and process design can successfully be done in this early stage.

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Figure 1. The PRECISE Production System (Schweizer 2012)
2) In the Integral Building Execution Planning (IBEP) phase, a process plan for the operations on the construction site is developed by the companies responsible for executing the work and their key suppliers in collaboration with the design actors. Here, one “neutral” actor without economic interests in the project, should moderate the workshop in order to develop the process plan. This actor should have the capability to extract relevant information from the participants in an efficient way. This workshop should not take more than half a working day and should not put undue strain the company’s time budget. In this phase, the Pitching concept is applied in order to synchronize all actors on site and to reach a constant work flow. The basic unit of the production schedule is set at one day or one week. Moreover, for integrating first and second tier suppliers the Takt Time principle derived from the manufacturing industry is used.

3) To implement the innovative execution planning approach (as described in the previous paragraph) a dynamic planning and controlling tool called “Dynamic Control Panel” was developed. This system should be accessible to all actors at the construction site and support the daily coordination of all involved crafts. Using the analogy to industrial production, the PRECISE production system is interpreted as work plan for realizing the product, which in this case is the building.

Case Study – Process Reengineering

Within the build4future project, a reengineering of two completed projects was done in collaboration with the participating actors: the architect, the project supervisor and some execution companies and suppliers. The PRECISE production system was used as a guideline, especially the Integral Building Execution Planning (IBEP) approach. The objective was to improve current performance by continuous improvement. To abstract scientific findings from analyzing specific scenarios, process models were created by taking into account existing restrictions.

Traditionally, time schedules are created using a so called push methodology. This means that the planning actor directs (pushes) the duration of the working tasks. In the IBEP approach, execution companies determine the task sequence and the work content in collaboration with the planning actor. Integrating the companies that are responsible for the execution into the planning process allows high workflow reliability to be reached.

Project Scenario 1 – Hotel 3.0

In the year 2008, the architectural studio Ralf Dejaco (b4f project partner) developed the building design and was responsible for the construction supervision of a hotel-expansion project with an overall cost of around 3 million Euros. The extension project consisted of twelve double rooms in the second basement level, twelve double rooms in the first basement level, an outdoor and indoor heated swimming pool, a new wellness area, and the expansion of the dining area.

Project Scenario 2 – Logistic Center 30.0

In the year 2009, a new logistics center for meat products with an overall cost of around 30 million Euros was constructed close to Bolzano, Italy. Here the b4f partner company Expan GmbH, which supplies light weight construction systems, was responsible for installing the industrial panels.

Case Study Procedure

The participating trades were divided in three different subgroups resulting in three different workshops: 1) trades concerning the core process construction (shell and interior construction); 2) trades concerning windows and facades; and 3) trades concerning the building technology.

Step 1: Process Planning

The step “process planning” starts with the division of the building into construction sections. This is done to reach a higher parallelization and to balance existing capacities in terms of available resources. When using traditional software tools for project management, like MS-Project, the network plan results from the time schedule. On the other hand, when using the IBEP-methodology, time scheduling is based on network planning. In this work, the MPM methodology was used. An appropriate activity sequence and duration was determined by focusing on the optimization of the whole process and not just individual processes.

Step 1.1: Development of Construction Sections

First, an interdisciplinary team (figure 2), divided the buildings into construction sections. The hotel building (figure 3) was divided into: 1) the rooms section; 2) the corridor area; 3) the engineering room (for wellness and swimming pool); 4) the swimming pool section; 5) the terrace area; 6) the dining room expansion, and 7) the roof of the dining expansion. Every section corresponds to a respective level (i.e. rooms second and first basement level, etc.).

The corridor area was considered separately from the rooms section, because it represents a kind of bottleneck. Different trades have to pass through it and work on it simultaneously.
Looking at the project scenario of the logistics center, a wider range of construction sections occur (figure 4). In addition, they change over the course of the project. For example, during the shell construction the application hall (NA) and the deep freezing store (TK) are considered as one main area, whereas during the interior construction they are considered separately because they contain a different type of technology.

After defining the construction sections, the job content in every section was estimated by the participating actors (REFA 1993). Job content means in this case the work type and the amount of work in terms of hours and number of needed resources.

Step 1.2 Elaboration of the Network Planning

Within the process reengineering a new methodology for network planning was developed (figure 5). For every task, suitable information, like the responsible craftsman (i.e. the electrician), the number of Pitches, the number of workers executing the task, and the location (construction section and level) is recorded. Predecessor and successor information are visualized with arrows. As explained before, the methodology is based on the MPM approach.

Considering the Project scenario 1 - Hotel 3.0 a number of 52 tasks were recorded in the network map (figure 6).
As in the EMPM methodology, cycles are taken in consideration (Kerbosch and Shell 1972). For example, scaffolding must be extended before concrete can be poured in the next level. Furthermore embedded supply chains, like the window installation process as described in Dallasega et al. (2013) are indicated in the map. Here, steps like taking the measurements of the structural openings by the window manufacturer on site for producing subframes with right dimensions are included in the map. In addition, drying times, like the floor screed drying duration, are emphasized. This means that no craftsman can step onto the pavement on the first day and that 2 to 4 weeks must pass before the floors can be put down.

To standardize and abstract scientific findings, process models were elaborated. A process model in this case refers to a standardized sequence of tasks, which can be adapted to different project scenarios by varying just its parameters. A practical example could be the floor structure. The sequence of activities for different project scenarios (a hotel building, an office building, etc.) might include the basic installation by a hydraulic specialist, the ventilation installation, the basic installation by the electrician, the installation of the compensation layer to protect the pipes, the interior plastering, the under floor heating installation, laying the screed and finally laying the floors.

**Step 2: Pitching**

The Pitching concept derived from manufacturing was used to synchronize different crafts on site. This allows the introduction of a steady workflow on site. As stated by Rother and Shook (2009), establishing a consistent, or level, production pace creates a predictable construction flow, which by its nature identifies problems and enables quick corrective actions to be taken. Based on Project 1 - Hotel 3.0, a new definition of “1 Pitch” suitable for the construction sector was developed. The consistent increment of work (Pitch) is calculated as follows:

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\text{Pitch} = \frac{\text{Job content (8h)}}{\text{Crafts team} \times \text{Construction section}}
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As visualized in equation 1, a standard increment of work specified as 1 Pitch was introduced in the Process Reengineering.

For every task, the respective amount of Pitches was calculated. A practical example could be the laying of carpet floor in Project 1. Every double room consists of 25 square meters of carpet floor and 5 square meters tiled floor (bathroom). According to a flooring expert who joined one project workshop, 1 person could reach around 25 square meters a day. This means that for the task “carpet floors”, 1 Pitch for every room was calculated. This means that a job content of 1 day should be calculated for the professional flooring expert (1 Person) in room nr. 1 located in the 2nd basement level. In other words this means that during this Pitch, just the professional flooring expert, works in double room nr. 1. Introducing this rule improves labor efficiency and safety because the different workers do not interfere with each other’s tasks. For 12 double rooms in the second basement, 12 Pitches have to be considered. If there are 2 professional flooring experts, 6 Pitches should be calculated.

**Step 3: Paced Time Schedule**

The Paced Time Schedule consists of a multidimensional view. Considering Project 1 – Hotel 3.0, construction sections are visualized on the y-axis, so called Pitches (Working Days) on the x-axis and the tasks and responsible crafts are visualized internally in the map (figure 8).

During the shell construction phase, the division is done in levels (second basement level, first basement level, ground floor, first floor, roof) and during the interior construction, the division is done within the levels (rooms section, corridor area) as explained in Step 1.1. Of pivotal importance and impact are the long drying times in the shell construction phase, which impede a parallelization of interior constructions (i.e. erecting interior walls). The work load for every craft-team is visualized with bars and includes the quantity of Pitches, the respective Task and the responsible craft-team (figure 7). Furthermore, the bar is referenced with the corresponding task in the Network Planning Map.
During the workshops, different priority rules were determined with the participating actors.

1) As one can recognize, in the interior construction phase a gradual planning was performed. The strategy behind this is that craft-teams start in one construction section and move in a flowing way through the whole building. Moreover, efficiency is reached through learning curve effects. A practical example is the laying of the floor screed, where the responsible craftsmen starts in the room-section, proceeds in the corridor area of the second basement level, restarts in the swimming pool section of the first basement level, and so on. So, a steady craft workflow, as visualized in figure 8 can occur during the construction project.

2) The corridor area was considered as the last location where work should be done. It was bypassed because of the drying times.

3) The different tasks/crafts were scheduled from the bottom to the top of the building. This was done to reach a high parallelization degree.

4) The engineering room was chosen as a buffer, which means that crafts were first scheduled in construction sections with a high job quantity, like the room section, and at least in the engineering room for balancing the labor capacity.

5) The construction sections were prioritized according to the job content. This means that tasks and crafts were scheduled first in the rooms section, second in the swimming pool area, third in the wellness area, and so on.

In summary, the Paced Time Schedule of the Project 1 - Hotel 3.0 was established by focusing on the capacity utilization of the involved crafts.

On the other hand, in Project 2 – logistics center 30.0, the focus was on capacity utilization of the construction sections (figure 9). The planning was done for the construction sections, trying to minimize construction stops. Here, the crafts are visualized on the y-axis, the Pitches (Working Days) on the x-axis and the tasks and the construction sections internally in the map.

The one-day Pitch was used because scheduling and controlling with a small time interval helps to recognize earlier if the whole process gets out of control. This allows necessary corrective actions to be carried out in time.

For the construction supplier, scheduling the whole project within a one day degree of detail allows an accurate foresight of work completion. This allows components to be ordered in time, facilitating a JIT delivery from production to construction.
Conclusion and Outlook

The paper introduced the new PRECISE production system which focuses on reaching process reliability in construction networks composed of SMEs. The name incorporates the philosophy that detailed planning can limit complexity and unpredictability on site and enable process reliability. In other words, in order to efficiently manage the execution process on site, it has to be planned in an appropriate/detailed way.

One part of the system, the IBEP was simulated within two existing project scenarios. Here the focus of design is switched from product development (building) to process development. Within reengineering, a guideline for reaching process reliability and sustainability was developed.

In on-going research, a real construction prototype will be planned and managed using the design methodology. Based on the PRECISE production system, an appropriate process control approach for small and medium sized projects will be developed.

To allow a JIT delivery of engineered-to-order components, the production (supply) process will be aligned and synchronized with construction on site. For this purpose, a prototype information management system will be developed in the ongoing b4f project.

Based on the prototype system, future research activities will be focused on appropriate Information Technology (IT) realization and implementation.

By designing the building execution process, the topic of “Interdisciplinary Design – Civil Engineering at the Boundary” was targeted, adapting different process planning methods from other industrial fields to construction. The implications for civil design research and education are that process planning methodologies should be integrated in design education, enhancing competencies and transferring know how for an efficient and sustainable construction management.

References


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