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# PROMOTING COLLABORATIVE CONSTRUCTION PROCESS MANAGEMENT BY MEANS OF A NORMALIZED WORKLOAD APPROACH

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## ABSTRACT

The research project »COCKPiT« - Collaborative Construction Process Management - aims at developing methodologies and tools to enhance time and budget control in construction projects, with a focus on small and medium-sized companies. The hypothesis is that the interplay of the three main phases of project management - planning, scheduling, and monitoring - can be improved by collecting highly detailed information early on in each phase, and making it available to the other phases at a high frequency. COCKPiT builds upon previous experiences in façade installation, where significant time and cost savings have been obtained by applying a normalized workload approach based on a collaborative process planning routine, an approach which is currently hardly supported by commercial project management tools. Thus, the objective of COCKPiT is to develop a methodology that supports i) collaborative process modelling as a basis for ii) a short-term rolling wave planning considering iii) real-time measurement of the progress on-site, to create highly reliable schedules and accurate forecasts. The focus of this paper is to present the conceptual fundamentals of integrating the modules of modelling, scheduling and

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monitoring, as well as involving the lean construction community to current considerations regarding the implementation in a self-containing IT-solution.

## **KEYWORDS**

Collaboration, Production System Design, Process modelling, Job sequencing, Monitoring

## **INTRODUCTION**

In traditional construction projects, budget overruns are often identified in a late stage when improvement actions cannot be applied anymore. This is partly caused by a coarse planning and management of the construction execution process. Therefore, the success of a project is often highly dependent on the competences of the responsible managing actors, such as site managers and foremen.

The Italian construction industry consists of a great amount of small and medium sized companies (SMEs) that makes the sector highly fragmented (Cacioli, 2017). As a result, in many building projects most of the participating companies are crafts with an artisanal organizational structure. Therefore, in many small and medium sized construction projects limited resources are available for planning and managing the execution process. Moreover, such projects are often characterized by participants with limited knowledge about methodologies and sophisticated IT-tools used for planning and management of the execution process.

The management of a construction project is traditionally organized in three main phases (Sears et al., 2008): 1) planning, 2) scheduling and 3) monitoring.

Planning is usually managed by considering historical experiences without involving the responsible actors for execution, resulting in schedules with unreliable information. As a practical example, important information regarding production rates for tasks and the needed labour resources to be able to perform these tasks within a specified time frame are often omitted. Scheduling and assignment of tasks on-site are often carried out in a non-systematic way or even just by acclamation of the foreman on-site. As a result, the focus on value adding tasks and the optimal saturation of workers on-site is seldom achieved. Moreover, a non-structured and detailed scheduling of tasks to be performed on-site makes it difficult to request the right type and quantity of material when it is needed. The monitoring of a construction project in a SME context is usually done by rough progress estimations of the foreman on-site. By operation of law, other important information, like workers present on-site, detailed labour-consumption, descriptions of performed tasks as well as weather conditions are recorded in the so-called construction log-book. However, this information is neither recorded in a quantitative way nor connected directly to the construction schedule. As a result, a frequent comparison of scheduled and actual data is not possible.

Therefore, the presenting researchers have identified a lack of systematic work planning and schedule routines which incorporates also an exact progress monitoring and is at the same time suitable for SMEs by means of easy-to-use IT-tools. The here proposed methodology to overcome these shortfalls consists of a normalized workload approach

embedded in collaborative planning routines, which is aimed to be transferred into a supportive IT-solution.

## **STATE OF THE ART**

At present, there are several production planning systems flying the flag of the lean movement, aiming to make work plans in the construction domain more reliable and robust, to increase productivity, to minimize waste and ultimately to contribute to satisfying project results from the customer's perspective. In this context, one of the most frequently used method in the execution phase of a construction project is the Last Planner System (LPS) (Kenley and Seppänen, 2010 in Gao and Low, 2014, 1261). LPS, as a method for work planning and control (Ballard, 2000), aims at creating and managing networks of commitments of involved players for successful project delivery. This is vital for on-budget and on-schedule completion of complex construction projects. The uncertainties arising from the typical long-term finishing dates of ordinary master schedules are integrated and consistently transferred to short-cycle work planning (Gehbauer and Kirsch, 2006). Process stability and thereby schedule reliability are indicated by means of the Percent Planned Complete value (PPC), which is the percentage of actually-fulfilled to committed-to-be-fulfilled tasks with respect to a defined timeframe. Hence, in an ideal – but unrealistic - case, the PPC value would be always 100 %. In addition to this methodological approach, LPS also includes a social process that can lead to open discussions among the parties and companies involved, joint learning for continuous improvement and an increase in mutual trust (Gao and Low, 2014; Hamzeh, 2011). However, even though LPS has been applied successfully in numerous construction projects (Kim and Ballard, 2010; Lindhard and Wandahl, 2013; Thorstensen et al., 2013), accompanied by significant process improvements, more predictable workflows and increased schedule reliability, it does not offer a direct possibility to measure progress in absolute numbers and therefore cannot be used as a stand-alone approach for monitoring and coordination of the construction site.

Recently, LPS often is applied together with the so-called Takt Planning approach which is referred to as a work structuring method (Bolviken et al., 2017; Frandson et al., 2014). Takt Planning and LPS can be seen as complementary in different aspects, since Takt Planning essentially can expand LPS's formal mechanism of commitment management with more standardized work batches and thus, contribute to continuous flow (Frandson et al., 2014). By aiming at disruption-free handovers between trades, Takt Planning would methodologically represent a 100 % PPC approach in the LPS perspective (Bolviken et al., 2017). For this goal, the formal methodology of Takt Planning makes use of clocked scheduling with time-harmonized work sequences and accordingly coordinated activities. To this end, construction projects are structured into so-called "Takt zones" by identifying repeatable and non-repeatable construction elements in advance of execution (Altner, 2016). The rhythm of the construction progress or, with other words, its "heartbeat" is determined by the so-called "Takt time". For reasons of practicability, a typical order of magnitude for Takt times in the construction domain is one working week (Altner, 2016). In each Takt zone, there is only one trade working at the same time for a precisely defined period of time, which reliably avoids mutual obstructions and reduces the

control demand for site management (Altner, 2016). When all involved trades consent to the alignment to a common work rhythm with a corresponding amount of work and work sequences, a very continuous working speed can be achieved (Friedrich et al., 2013 in Haghsheno et al., 2016, 57). Insufficiency of this approach consists of the almost exclusive applicability to repetitive construction works. In fact, the utilization is very common in almost identical work sequences with high recurrence rates (Haghsheno et al., 2016), whilst non-repetitive environments are barely being considered due to inherent methodological limitations. Notwithstanding the fact, that recent endeavours have been made to find repetition in non-repetitive construction works on the basis of work density in order to circumvent this shortcoming (Tommelein, 2017), practical applications of such cannot be found often and the conceptual framework is not available in textbooks yet.

Another production planning system that is highly regarded but also used primarily in repetitive construction projects is the Location-Based Management System (LBMS) as a recent methodology based on Location-Based Planning (LBP). As opposed to activity-based methods (i.e. CPM, PERT), LBP focuses on tasks that repeat in different locations to reduce the movement of resources in space. Thus, location is considered a critical variable, on par with time and activities. LBMS is based on the Location Breakdown Structure (LBS), rather than on the traditional Work Breakdown Structure (WBS). In the former, the locations where the work is performed are broken down to a certain level and hierarchically organized. Logical constraints are established through a “layered CPM logic” (Kenley and Seppänen, 2010), non-hierarchical and implementable with the same forward-backward passes of the CPM, so that the focus is again on location rather than activities. LBMS has been proven successful at implementation in reducing project duration and balancing resource usage (Seppänen et al., 2014). Nonetheless, the methodology does not consider learning from process feedback for optimizing the planned schedule and updating the forecast (Dallasega, 2017), since Kenley and Seppänen (2010) argue that, the learning curve in construction operation remains mostly linear after the very first improvement. Moreover, to a similar extent as Takt Planning, LBMS can also be considered complementary to LPS, since LPS covers social aspects in a production planning system, which are being mostly neglected in LBMS (Seppänen et al., 2010). The overlooking of these social considerations makes either LBMS or Takt Planning less suitable in the context of SMEs, where fragmentation of actors working on the project, and thus communication and sociality, are crucial factors.

In addition, ongoing current investigations within the scope of the COCKPiT research project have shown that, until today, SMEs tend to use exclusively MS Excel spreadsheets for work planning or deal with MS Project schedules visualizing Gantt charts generated on a CPM basis. Therefore, a software-supported application of the Lean Construction methods briefly outlined above – even though partially existing on the market but almost solely used by major companies - is practically not to be found in SMEs day-to-day use. This underlines the necessity of an IT-supported solution adapted for SMEs, which enables intuitive access to LCM-based construction site management and at the same time overcomes current methodological shortcomings.

## THE COCKPIT PROJECT

The here proposed approach for an improved collaborative construction process management respects the advantages of the Lean Construction methods presented above, as well as adapts and expands them by significant new aspects.

Looking at LPS, essential for its successful application is an appropriate definition of the single tasks at the execution level by the Last Planners. Ballard (2000) mentions the following important features: (1) The task must be well defined, (2) tasks must be arranged in the right sequence, (3) the selected extent of work must be right and (4) defined tasks must be feasible. But even underlying these principles, the open question remains: How do we have to specify workloads quantitatively? The COCKPiT approach proposes a normalized workload approach (NWA) which consists in the first step of collaborative estimation of production rates considering the expertise of Last Planners. These production rates are then normalized to a certain time interval (e.g. one working day). This principle of normalizing workloads is referred to as "pitching" known from Lean Manufacturing and has already been worked out in previous studies and successfully applied to façade construction (Dallasega et al., 2015, 2013). The dimension of the pitch for a specific construction area (CA), and a respective task, considering the associated quantities and crew composition for a certain time interval, is the following:

$$Pitch(CA_i, Task_j, Crewsize_k) = \frac{Quantity_{ij} [MU_j]}{time\ interval} \quad (1)$$

The dimensional analysis in formula (1) denotes the definition of a pitch as the quantity indicated in the respective MU of the task  $j$  (e.g. 20 m<sup>2</sup> of parquet) that can be installed by the dedicated crew of the size  $k$  (e.g. two workers) in the CA  $i$  within a defined time interval (e.g. one working day).

$$Pitch_{i,Parquet\ laying,2} = \frac{20\ m^2}{working\ day} \quad (2)$$

An inherent advantage of the NWA over LPS is that the job assignments have a clearly defined quantitative and understandable extent. The precognition of single and total quantities (e. g. via quantity take-off from the BIM model) enables accurate determination of the construction progress at any time in almost real time (on condition that the extent of the pitch completion is reported daily). Extending a production system like LPS with this essential functionality, known key performance indicators (KPI), such as PPC describing process stability, can be maintained without incident.

Taking the paced schedule created through the pitching concept into account, analogies of NWA to Takt planning in construction can be seen apparently, whereby the chosen time interval (e.g. one working day) can be interpreted as the Takt time in which one pitch of a certain task should be fulfilled. Notable difference to Takt Planning here is that after one "Takt", the crew does not have necessarily to move on to the next planned location, given that the number of pitches varies from different trades and CAs. This results in a high

degree of flexibility, which in turn does not limit the applicability of the presented approach to repetitive projects only, but potentially also suits non-repetitive projects.

It is this application flexibility which is going to be investigated in the context of the COckPiT project by extending the promising approaches from façade construction (Dallasega et al., 2015, 2013), often characterized by clear repetition patterns, to HVAC installations and shell constructions works.

At the same time, however, high degrees of freedom in terms of project type require great diligence and coordination work to parallelise and balance the workers on the construction site to achieve a continuous workflow that takes into account the varying "pitch-load" of the individual CA's and trades. To this end, the approach of collaborative process planning with responsible Last Planners is pursued with similarities to the phase planning of LPS, which distributes competences regarding effort estimation and task sequencing in a bottom-up manner to executors. In previous projects, this was achieved with the aid of paper-based documents, and it shall be prospectively carried out digitally supported within the context of the COckPiT approach in the designated modelling module. Herein, once defined process models, containing information pertaining to dependencies of CAs, tasks, crews etc., as well as known quantities (from plans or BIM), allow automatic scheduling suggestions of location-based tasks by means of the scheduling module, as soon as start and end dates have been brought into the system. The schematic flow of the NWA in the COckPiT project is illustrated in Figure 1, indicating also the feedback loop by means of the monitoring module.

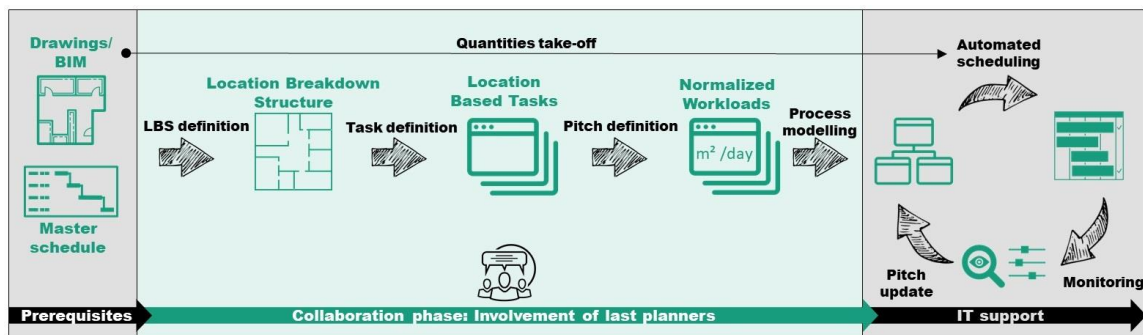


Figure 1: Schematic workflow of NWA

Because NWA interprets locations also as a logical information container for the definition of the pitch and aims for continuous flow of work, clear similarities to the LBMS can be identified as well. In the context of NWA, such similarities are again methodically extended for the sake of completeness of the proposed approach. Systematic feedback loops are incorporated to update initially estimated production rates and labour consumption automatically (pitch update), which in turn triggers a very targeted continuous improvement process (CIP). In addition, employees' confidence in the methodology is systematically increased, because the generated schedules for defined short-term look-ahead windows only include an extent of work that corresponds to their own performance, that has so far been monitored. If daily goals defined by the pitch cannot be met,

analogously to LPS, reasons for non-completion (RNC) can be collected, bringing with it all well-known advantages in terms of enhanced transparency and CIP.

## **GOAL & ROADMAP**

The COckPiT project's goal is to develop a tool for collaborative process management tailored to SMEs needs, with the aim of increasing their competitiveness on the market. Therefore, it should not only contribute to successful project delivery and improved means of communication between actors, but also cover the needs of small-scale construction projects, usually distinguished by a low level of repetitiveness and unique traits. Within the presented research project this will be aimed at covering the three main building phases: shell, envelope and interior. The main outcomes to this project will be a NWA-based methodology, as the theoretical framework for an ensuing IT-prototype, to support three main aspects: i) a modelling of the process, comprehensive of all relevant project information, ii) a short-term scheduling module, suggesting possible schedules automatically, which are computed based on the information in the model in (i), and iii) a real-time progress monitoring tool, to both control the site operations and progressively adjust the model (i), and subsequently the schedule (ii) to the concretely achieved pace.

To increase the practical feasibility of the outcome, SMEs from Northern Italy have been engaged in the research stage, to provide the initial requirements and continuous iterative feedback on the methodology during the development stage.

## **MODELLING**

The modelling module foreseen in COckPiT aims at supporting the collaborative definition of the execution process. More precisely, this corresponds in defining i) the main tasks that need to be executed, and for each of such tasks ii) the resources required by it, iii) the locations where to perform it, iv) the pitch, and v) the dependencies (such as precedencies) on the execution of the tasks in the locations.

The aim of the project is to develop a methodology and a formal framework supporting the definition of a process model. This latter is often ignored in construction, where a process is modelled by directly defining a plan. The difference is that a process model would represent only the requirements that a plan must satisfy (e.g., task A must be performed in location I any time before task B is performed there), without already committing to sequences and dates on the execution of the tasks. Since a model defines a number of constraints on the execution process, the overall approach results to be more flexible when unexpected events and delays occur. In these situations, indeed, a reschedule of the activities is often needed. By relying on a model, every reschedule that satisfies all the constraints is a possible one. By relying on a plan only, instead, it is not clear how it can be changed. For instance, when two tasks are planned one after the other, it is not clear whether this is because of a requirement which prevents them to be scheduled differently, or it is because of a scheduling choice that can be changed. Additional knowledge (e.g., from the foreman) would be needed in these cases, which prevents the development of (automatic) IT-based tools. The definition of a model involves different competences from the different trades participating to the project. Therefore, great benefit can be achieved if it is defined collaboratively. To this aim, within the project a graphical language to support a process model definition will be defined, along the line of Marengo et al. (2016).

## **SCHEDULING**

Based on the process model collaboratively defined, short-term schedules can be derived. A short-term schedule represents a commitment to one among the possible plans compliant to a process model. Weekly, the foreman on-site defines for a short period of time (day or week), the tasks to be executed, the locations where to execute them and forms and assigns the crews to the tasks. To compute the duration of a task and the number of labour resources needed, he relies on the concept of pitch defined in the process model, which contains implicitly the commitment of the executors due to its collaborative, bottom-up determination. Importantly, the schedule for a certain period is based on up-to-date information on the executed tasks (information that is collected in the monitoring phase). This ensures that duration of tasks can be computed in a reliable way reflecting real conditions on-site, and that only tasks that can be executed (e.g., whose predecessors are completed) are scheduled for the time period.

The project aims at developing IT-tools for this module, both supporting a manual definition of a schedule and automatic generation of them (optimizing some criteria of interest). This will be done by relying on constraint satisfaction techniques.

## **MONITORING**

The monitoring module aims to control the construction progress in a quantitative way and in a real-time frequency. Here, the pitches will be used to measure the construction progress by collecting information with regards to which extent the pitch of every activity has been actually achieved. The approach allows a reliable measurement of the construction progress for repetitive as well as non-repetitive working environments. Up to now, experiences with façade installations (Dallasega et al., 2015, 2013) showed that in repetitive working environments the construction progress measurement could be performed by considering the measuring units of single façade fields. In a non-repetitive working environment, a project with a high variety of construction locations, in terms of size and technology content, differentiated units of measurement must be determined. Here, the aim is to define for every task specific measuring units (like number of pieces, square meters and running meters). As such, the experiences within the domain of free-form surface façade installations have shown that even in non-repetitive projects a reliable measurement of the construction progress becomes possible (Dallasega et al., 2015, 2013).

Moreover, pitches are used not only to measure the construction progress in a quantitative way but also to forecast in a reliable way the needed job amount until project completion. Previous research has shown, that by applying the pitching concept to forecast the needed job amount until project completion, the planned and used amount of labour can be kept in sync and as such budget overruns can be avoided (Dallasega and Rauch, 2017).

## **CONCLUSION & OUTLOOK**

In this paper, the COCKPiT project and the underlying methodology of a normalized workload approach incorporated in the three modules of modelling, scheduling and monitoring were presented. In the course of this research project, the approach was presented already extensively to the companies participating and the benefits of a model

that potentially supports automatic scheduling were acknowledged consistently. However, it was argued that the modelling part should be reminiscent of known work steps such as creating a Gantt chart to reduce the risk of rejection by later users and take place as far as possible in the backdrop. Later to be developed graphical user interfaces (GUI) should be similar to location-based Gantt charts, which also can serve as a monitoring user interfaces. Collected information should constantly adapt and improve the underlying model but hand over as little effort as possible to the user.

First prototypes for the individual modules are currently being developed on an MS Excel basis and fed with real data from the companies involved. It is important to find out how the modelling module can be built up as discreetly as possible and how the granularity of the individual tasks for the different trades must be defined to facilitate effective scheduling and monitoring. Feedback from construction supervisors and foremen is currently being collected directly on the construction sites. This close and constant exchange with the companies is of utmost importance to quickly develop operational prototypes in order to support the hypothesis that a collaboratively determined and normalized workload approach helps the practitioners from SMEs to deliver construction projects in a more timely and cost-efficient way. Furthermore, it will be investigated which additional KPIs could be aggregated from the monitored data to support the control of a construction project to identify problems in advance and to implement appropriate improvement actions in time.

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