COCkPiT

COllaborative Construction Process ManagemenT

Free University of Bozen-Bolzano – Fraunhofer Italia research s.c.a.r.l.

Contents

1 Relevance of the Project

1.1 Context of the Project

Globally, the construction industry is one of the main fields of economy. In the province of Bolzano the building industry makes an important contribution to the local economy. Construction contributed about 6.7% to the gross value added at basic prices in the year 2013 [4]. Considering Italy and specifically the province of Bolzano, this sector consists mostly of small and medium sized enterprises (SMEs), being therefore highly fragmented. Furthermore, a peculiarity of the construction industry is that every project requires a new constellation of project participants. As a result, this leads to a high effort for coordinating the different project-involved companies. However, in small and medium sized projects the available budget is limited which leads to superficial planning and management of the execution process.

In the province, construction is one of the industrial sectors that has been affected most by the last economic crisis. Considering the period from January 2012 until January 2013 the construction industry and craftsmanship suffered a labor variance of -3.3% and -3.7%, respectively, which represents the biggest labor market decline among all sectors of the economy [9]. In comparison to other industrial sectors, construction still suffers from a low productivity rate, a weak usage of resources and delays. Figure 1 shows the principal indicators of the economic sectors in Italy for the period from 2008 to 2012 [2]. The chart "value added per employee" shows the big productivity gap between the manufacturing and construction industries. Furthermore, in construction also investments and labor costs per employee are much lower than the manufacturing industry.

In addition, construction is prone to specific challenges, such as the variability of customer requirements, unpredictable weather conditions and finally, yet importantly, the constant need to set up an effective collaboration between different project participants. Usually, SMEs would prefer to avoid building consortia managed by general contractors, to avoid that in case of a collapse of the general contractor depending subcontractors (most of the time SMEs) are also taken in bankruptcy. To facilitate collaboration between different actors, digitalization, as strongly discussed in manufacturing under the label "Industry 4.0", will also be useful in the construction industry. The aim of the fourth industrial revolution (Industry 4.0) is to organize manufacturing plants as cyber physical systems (CPS) that interact over the Internet-of-Things (IoT), thus achieving real-time collaboration between systems and humans. This approach has the potential to bridge the gap between the two most innovative trends in the architecture, engineering and construction (AEC) sector today: Lean Construction and Building Information Modelling (BIM). These days, most of the research on BIM in academia and industry focuses on improving the building design and pre-construction planning [27]. Less effort has been invested in developing tools to support construction management on-site and to integrate those into BIM [27]. Most of the commercial tools

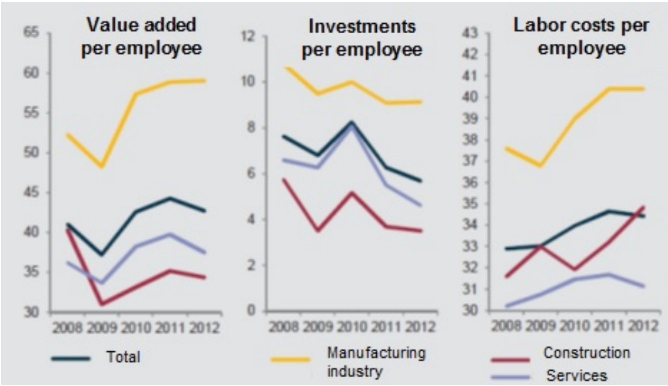

Figure 1: Principal indicators of economic areas in Italy (2008-2012) [2].

used in construction project management, such as Microsoft Project and Oracle Primavera [19, 23], are based on techniques like Critical Path Method (CPM) and Earned Value Analysis (EVA). They do not allow for collaborative process planning or, in other words, task negotiation and planning between different companies. Neither do they allow one to take into consideration the specific requirements of a building project. Especially, one cannot monitor in detail the construction progress on-site. Traditionally, construction management, especially the coordination of different crafts on-site, is performed with little IT-support, depending on the individual skills of the responsible foreman or supervisor.

1.2 Challenges Faced by the Proposed Project

The main challenge of COCkPiT is to support SMEs in efficiently managing construction projects, that is, to provide tools and methodologies to *i)* manage collaboration and *ii)* organize the work on-site. The primary challenge is to maximize the usage of resources (labor, equipment) and so to reduce the overall cost. Another challenge is to decrease delays and so the overall project duration. Among others, a challenge is to make real-time information about the overall construction progress available and to organize the daily/weekly work on-site based on the actual progress. Finally yet importantly, the methodology and IT-support must be suitable for scheduling and monitoring both repetitive and non-repetitive construction projects. Because the methodology and IT-support are to be used in small and medium-sized construction projects, the effort for using the methodology and the IT-support should be reduced to a minimum.

1.3 Response to Challenges, Exploitation of Opportunities, Novelty

The methodology we will develop focuses on the construction of new buildings. It will be suitable to be implemented in an IT-support system, which uses technologies like touch and mobile devices. In previous work, we identified three main phases of a conventional construction project [10]. In the *skeleton* phase the shell of the building is erected, comprising masonry and carpentry. In the *envelope* phase the shell is closed, by fixing the facade, windows, doors, etc. In the *interior* phase all final installations take place, e.g. heating, ventilation and air conditioning (HVAC), piping, etc.

A major novelty in COCkPiT will the so-called *collaborative process modeling*. Here, the construction execution process is defined by actors which are responsible for the execution on-site. As a result, the execution plan will be more reliable. Furthermore, different execution strategies for an optimized workflow can be negotiated between different trades. During a previous research project, build4future, a first approach for collaboratively modeling a construction process was developed and tested by re-engineering completed construction projects [11]. For each project, a process model was developed that identified the tasks, their interdependencies, and the resources required for them. The models were developed at collaborative workshops with the project partners, using a magnetic white board (and thus without IT support).

In build4future, the proposers developed a basic technique for process modeling, scheduling and monitoring, called PRECISE (= Process REliability in ConstructIon for SmEs), which integrates several lean management approaches suitable for the construction industry to achieve process reliability within networks of SMEs [11]. Based on PRECISE, we sketched in a previous paper an approach for supporting the execution management of small and medium sized projects in the AEC-industry [10], which will be taken as the starting point for COCkPiT. In COCkPiT, we want to develop a framework that comprises three modules:

1. A graphical notation for **modeling** the principal components of a construction project (locations, tasks, crews, material, etc.) and of their dependencies with each other.
2. A mechanism for **scheduling** that takes account of those dependencis and that can handle the high variances in the construction industry (e.g. customer changes, weather conditions).
3. A mechanism for **monitoring** the progress of the project in real-time, such that: *i)* the supply chain of building components can be synchronized and *ii)* delays can be identified early on in the project, allowing one to prevent budget overruns.

Our approach relies on the concept of "pitches", which was introduced in the manufacturing industry and that we adapted to construction [10]. A pitch defines, in this context, the amount of construction locations (e.g., 2 rooms) for a specific crew (composed of a minimum number of workforce e.g., 3 persons), to be completed in a certain period (e.g., 1 day/week). They are the glue that connects the modeling, scheduling and monitoring modules which, as shown in Figure 2 are tightly connected one to another. Pitches are estimated in the modeling module and then used as a quantitative unit to schedule and monitor the construction progress and to describe the productivity of crafts for certain tasks. During scheduling and

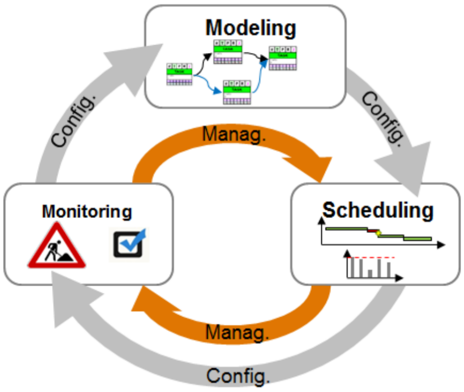

Figure 2: Relations between the three modules of modeling, scheduling and monitoring [10].

monitoring they are continuously updated according to real data on-site. The approach breaks the erratic assumption of most scheduling methodologies, where the relation between time and completed construction units is assumed to be linear (see "Comparison with the State of the Art"). The challenging part here is to develop an approach suitable to treat also non-repetitive processes, which typically occur in interior construction, especially for the HVAC trades.

Collaborative Process Modeling. In collaborative workshops, the companies responsible for executing the work on-site model the execution process. As a preparation, the building structure is subdivided into physically controllable parts, called "construction areas." The subdivision into areas will typically depend on the main phases skeleton, envelope, and interior (see [10]). During the workshop, the participating companies collaboratively define the necessary tasks, based on the areas and according to the building design (technology content). Furthermore, constraints on the order in which the tasks can be executed and other dependencies are identified. For every task, the pitches are defined and the effort needed for them is estimated by the participating experts. In our reengineering exercises in build4future and in subsequent real-world projects, we ran the collaborative process modeling workshops without IT support.

As shown in Figure 3, taken at the workshop for the project Expansion of the Hospital of Bolzano, we used magnetic white boards, where tasks and construction areas were modeled by means of magnetic cards.

During the research project MoMaPC (Modeling and Managing Processes in Construction), which is internally funded by the Free University of Bolzano, we started to develop a formal basis for process modeling in construction [18]. We would take this as starting point and extend it to cover all construction phases (Skeleton and Interior) in the research project *COCkPiT* .

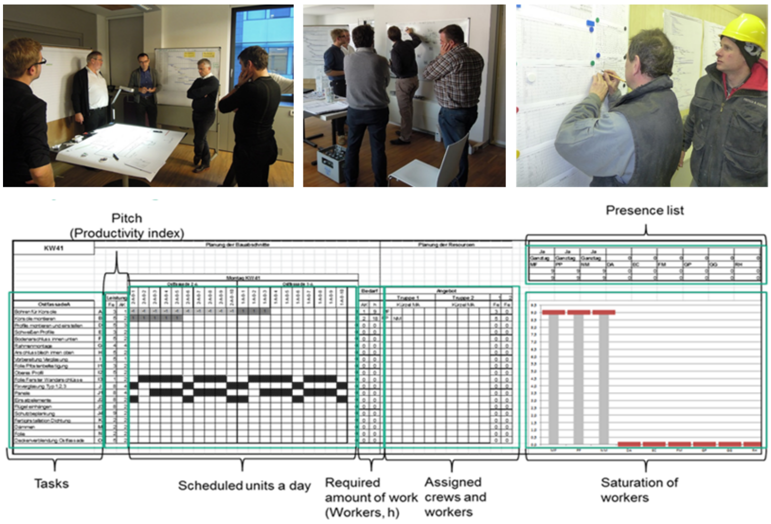

Figure 3: Application of the Modeling, Scheduling and Monitoring approach to the expansion project Hospital of Bolzano, in collaboration with Frener&Reifer GmbH.

Scheduling. Within the Scheduling part the data collected in the Collaborative Process Modeling workshops is used for defining short-termed working plans to be performed on-site. Here, the concept of Rolling Schedules is used, which is well-known in the field of industrial engineering [30]. We developed and applied this concept successfully within two case studies in collaboration with Frener&Reifer GmbH, which is explained in detail in [12]. Summing up, it means that schedules are elaborated based on the available capacity (labor) on-site for short time intervals (e.g. one day or one week). The most important aspect is that scheduling for one period ($t = 1$) is done based on the work performed in the previous period ($t = -1$). As a result, this allows to consider variations on-site. Within *COCkPiT* we want to understand how to extend this Rolling Scheduling approach to trades working in the phases skeleton and interior. Until now we used a limited IT-support by means of ad-hoc developed MS-Excel spreadsheets to schedule and monitor the construction execution process for facade installation. In Figure 3 the MS-Excel based spreadsheet, which we developed and applied in the Expansion Project Hospital of Bolzano for daily scheduling, is shown [10].

Construction Progress Measurement and Monitoring. Here, the experts responsible for the execution process report in a daily time interval the performed work on-site. The performed tasks and the responsible crews composed of specific employees, the completed construction areas and the used amount of hours are recorded. Furthermore, if the defined amount of pitches (the productivity of tasks) was not reached, a plausible problem description has to be registered. As a result, this allows to monitor in real time (daily-frequency) the construction progress. We experimented this approach with the company Frener&Reifer GmbH in the construction projects, Expansion of the Hospital of Bolzano and Softbridge located in Oxford [12]. As a result, we discovered that this approach is very useful for performing the scheduling based on reliable data. Furthermore, it is very important to understand early on if the project is going on well or not, so as to be able to take improvement actions in time. Until now, we developed and tested this approach with limited IT-support. Considering the collaboration with Frener&Reifer GmbH in the Expansion Project Hospital of Bolzano the crew leaders filled in by hand their performed work at the end of every day. Once a week, usually Monday morning the installation foreman registered in the MS-Excel spreadsheet the forms filled in by the crew leaders and the MS-Excel spreadsheet calculated Key Performance Indicators (KPIs). So, on a weekly bases information on the budget (e.g. over-budget, under-budget or on-budget) was sent to the headquarters of the company (Project Management) and visualized on a board in the construction container. The approach is explained in detail in [13] and visualized in Figure 3.

Comparison with the State of the Art Considering the Collaborative Process Modeling, a well-known methodology for improving the coordination of different trades on-site is the *Last Planner System* (LPS) [7]. The original approach is based on four levels of scheduling: *i)* the Master schedule, *ii)* the Phase or "Pull" Planning, *iii)* the look-ahead planning and *iv)* the weekly or daily work planning [7]. The LPS approach incorporates a feedback loop from site where in weekly meetings the so-called Percent Planned Complete (PPC) value is measured. However, this indicator is only used to analyse the amount of tasks performed in relation to the tasks scheduled. As a result, the monitoring of the construction progress is not explicitly conceived in the approach. Furthermore, initially the methodology was developed without any IT-support for collaborative planning, scheduling and monitoring which makes its application time expensive and therefore not suitable for small and medium-sized construction projects. Most of the commercial systems for Construction Project Management are based on the CPM [14, 22], the Program Evaluation Review Technique (PERT) [22] and EVA [16]. Such approaches are called "activity-based" scheduling systems, because the construction locations are considered marginally. As a result, by using those kinds of scheduling systems a detailed measuring of the construction progress becomes difficult. On the other hand, there are approaches called "location-based" scheduling methodologies where the main entity consists of locations. The first "location-based" approach was developed by Adamiecki and it was used as a construction management system for the Empire State Building in 1932 [1]. Today, the most famous "location-based" approach is the Location Based Management System (LBMS) developed by Kenley and Seppänen [16]. The commercially used system VICO software implements the LBMS methodology [32]. The LBMS approach concentrates mainly on the movement of resources through locations. It focuses on tasks, which repeat in multiple locations or in other words on a continuous workflow. However, the approach shows its limits considering the real-time monitoring of the construction progress. It does not incorporate a systematic feedback loop of performed work into scheduling. This is a fundamental precondition for making reliable forecasts as well as to monitor in real time the construction progress.

In literature two basic approaches for scheduling repetitive construction projects can be identified: the Line-of-Balance (LOB) and the Flowline approach. According to [3] different extensions of the basic LOB approach were developed. According to [25] the basic assumption of the LOB approach is that the production rate of an activity is considered linear in terms of units per time. Furthermore, in [25] the authors argue that the LOB approach requires that tasks have a "single equal duration", the same "resource usage" and have to be executed in a "fixed production order", which obviously limits its application, especially in complex one-of-a-kind constructions. Similarly, the flowline approach is used to depict workflow within construction locations showing explicitly the sequence of construction locations. However, as similar to LOB the relation between time and tasks performed in construction locations is linear, which limits its application in conventional construction projects. Furthermore, these scheduling approaches assume that repetitive construction projects are composed of identical construction units. Of course, this does not fit for so called repetitive construction projects' and even less for "one-of-a-kind projects" (non-repetitive construction processes). In addition, there are few and just prototypical approaches conceived for scheduling and monitoring non-repetitive construction projects [25, 17].

Based on the results of the research projects build4future, MoMaPC and the collaboration with the company Frener&Reifer GmbH we started to investigate if there are SW-tools on the market able to satisfy the identified requirements. In Table 1 our initial research about the identified requirements and 10 well-known software tools for Construction Management is shown. Here, the evaluation -1 means that the considered software does not satisfy the requirement. The evaluation 0 means that the software tool considers the requirement. The evaluation +1 means that the requirement is completely fulfilled by the software. The following sources were used to evaluate the ten identified software tools: Microsoft Project [28], Oracle Primavera [23], BIM 360 [5], Nevaris [20], Tekla [31], Vico software [33], ConstructSim Planner [8], Sablono [26], Sitesimeditor [29], Workplan solutions [34]. As a result, it emerged that at the moment there is no commercial software tool on the market able to consider all requirements in a holistic way.

1.4 Collaboration Between Institutions/External Partners

The project proposal *COCkPiT* builds on an ongoing collaboration between the Free University of Bozen-Bolzano (UniBZ) and Fraunhofer Italia research s.c.a.r.l. (Fh). More in detail, the collaboration between the Faculty of Science and Technology (FaST) and Fraunhofer Italia, specifically the research team Process Engineering in Construction (PEC), started during the research project build4future. Here, a first Microsoft Excel based prototype for scheduling and monitoring the facade instal-

Considered requirements for:	MS Project	Primavera	BIM 360	Nevaris	Tekla	VICO	ConstructSIM	Sablono	Sitesimeditor	Work PLAN
Collaborative modeling of the construction process	-1	-1	0	-1	0	-1	0	0	0	-1
Scheduling to organize the work on-site	0	1	-1	0	-1	0	0	-1	0	0
Monitoring to track the progress in real-time on-site	0	0	0	0	-1	0	0	0	-1	0
Total	**-1**	**0**	**-1**	**-1**	**-2**	**-1**	**0**	**-1**	**-1**	**-1**

Table 1: Evaluation of existing software solutions for Construction Management.

lation process was developed in collaboration with Frener&Reifer GmbH during the Expansion Project Hospital of Bolzano. At the same time a collaboration between the PEC team and the Faculty of Computer Science (FaCS) started with the joint supervision of student projects, leading to a scientific publication [10]. Afterwards, a collaboration between FaST and FaCS started leading to the definition of the research project MoMaPC, within which a first formal approach for modeling construction processes and a web application as demonstrator for the scheduling part was developed [18]. Until now, the developments have just been focused on facade installation. To consider the whole construction project (the phases skeleton and interior) two leading construction companies in the region have been integrated into the current proposal. Two experts from each participating company, specifically an experienced project manager and site manager will participate into the project as members of the Industrial Advisory board (see Section 2.3). Unionbau GmbH acts as a competent partner in the skeleton construction phase being an expert of masonry and carpentry. Frener&Reifer GmbH is one of the international leading companies in the field of free-form facades acting as a competent partner in the field of building envelopes. Atzwanger AG operates successfully in Italy and Europe in the field of HVAC and the group provides valuable experience and knowledge for the phase interior construction. As a result, the project organisation covers the main interfaces within a conventional construction project. Figure 4 shows the planned organisation of the proposed project *COCkPiT*.

COCkPiT's team members have been carefully selected to cover all the competences needed in the three main areas in which the project develops: process modeling, industrial engineering and construction management. Prof. Nutt's research focuses on data management, data quality and on process modelling and reasoning. Dr. Montali is a well known researcher in the area of process modelling and management. Prof. Matt will supply competences on industrial engineering and Dr. Rauch's research experience concerns design and scheduling of industrial systems. The main contributions of FaCS within COCkPiT are then on process management and modelling and IT-development. FaST contributes its expertise in the field of industrial engineering and the main responsibilities are the development of the framework and the methodology. Here, well-known approaches and principles from industrial engineering, especially the research area Industry 4.0 are

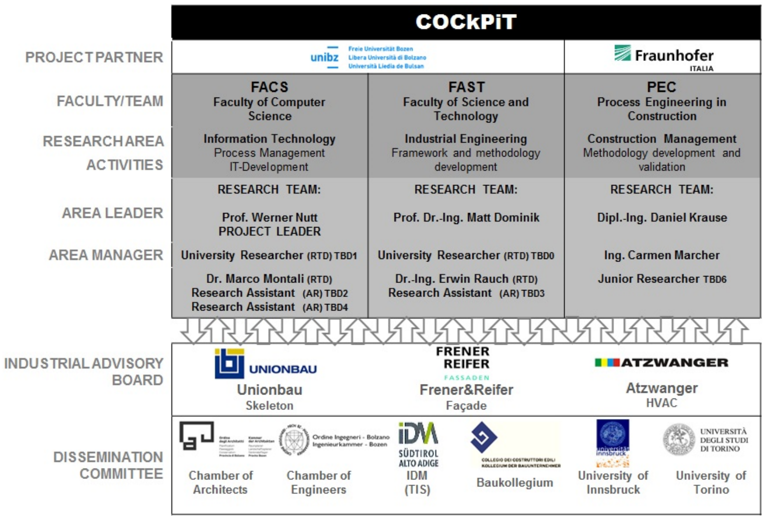

Figure 4: Overview of the organisation of the *COCkPiT* project proposal. **TBD** = To Be Determined (for the staff that will be hired or assigned later to the project).

applied to construction. The research team PEC acts as experts in the field of construction management. Because Fraunhofer works in the field of applied research, PEC collaborates in the development of the methodology and the design of the prototype. Especially, PEC is responsible for validating the developed approach and the prototype in close cooperation with the participating companies. Finally, we will set up a Dissemination Committee for publicizing the reached results (see description of WP 2).

2 Objectives and Activities

2.1 Objectives

The overall goal of the project is to provide methodologies and IT tools to support an efficient management of construction processes, supporting a collaborative and real-time approach. This can be broken down into the three objectives below.

(Obj 1) Framework, methodology and tool to support collaborative process modeling. In the project *build4future* we saw the advantages of a collaborative approach to process modeling in construction. To support this activity we will refine that approach by developing a *formal framework* that allows one to represent *i)* the architectural structure of a building, *ii)* the tasks that need to be performed to erect it, and for each such task *iii)* the resources required by it, *iv)* the construction areas where to perform it, *v)* the productivity of the workforce (the "pitch"), and *vi)* the dependencies among these items. The framework will be general enough to represent the different granularity levels of the skeleton, envelope and interior construction phases. To help modellers apply the framework we will define a *methodology* that will guide them in the definition of all of the above steps.

We will develop a prototypical *graphical software tool* that replaces the magnetic boards used in *build4future* with digital touch boards and laptops. The prototype will support modeling according to the new framework and the methodology. Moreover, it will take advantage of the digital representation of models, allowing one to reuse previous models, to modify models, and to zoom into details as wells as to automatically check for consistency.

(Obj 2) Methodology and tool to support short-term capacitive scheduling. In order to be reliable a schedule should satisfy the following characteristics. It should be *i)* defined over a *short-term* temporal window, thus allowing one to discover delays early enough to define recovery plans; *ii) capacitive*, meaning that it must consider resources actually available on-site (e.g. workers actually present on-site on a certain day); *iii) rolling*, that is, it is constantly updated with data reporting the progress on-site. This, however, requires a high number of details to be considered, which, without adequate IT support, complicates the definition of a schedule. To support this activity we will first develop a *methodology* for rolling capacitative short-term scheduling. This will be developed in a coherent way w.r.t. the modeling framework and methodology and, in particular, will be based on the concept of pitch. We will develop a *SW prototype* that support the scheduling and that is fully integrated with the modeling and the monitoring modules. Accordingly, it will perform consistency checks w.r.t. constraints from the process model (e.g., dependency satisfaction, needed resources for a task), it will suggest possible schedules (optimal w.r.t. some target criteria) and it will consider the actual progress of the tasks (e.g., a task cannot be scheduled in a location where it is already finished).

(Obj 3) Methodology and tool for real-time measurement of the progress on-site. In COCkPiT, monitoring is fully integrated with modeling and scheduling.

Specifically, scheduling is performed based on current information and on a reliable view of the overall work progress. To ensure that the progress is measured coherently for the different tasks and by the different workers, we will develop a *methodology* that will guide a worker in tracking the amount of work performed.

The methodology will foresee for each activity a responsible who is in charge of reporting, at the end of specified time intervals (such as days, weeks, or months) the progress reached and the problems encountered. The methodology will aim at measuring the progress for each phase (skeleton, envelope and interior) in almost real-time.

We will develop a *SW prototype* for supporting the monitoring of the progress on-site. Workers will use mobile devices (e.g. phones, tablets) to track the execution of the tasks in locations, scanning RFID or QR codes whenever available. The system will elaborate the data and present statistical information such as the comparison of the performed and the scheduled work, or forecasts on the achievement of established milestones. Thanks to this approach, possible sources of delay will be discovered early on so that corrective action can be taken quickly, thus limiting possible delays or cost overruns.

2.2 Outcomes

The overall outcome of the project will be *i)* a methodology and *ii)* a tool suite to support the collaborative and real-time management of construction processes. More concretely, this corresponds to the development of the following three items:
*1. A **framework** and the corresponding formal basis for process management.* The framework will lay the formal basis for process management and, in particular, for process modeling. To this aim, we will define a graphical language inspired by the one developed in *build4future*, which will cover all three phases of the construction of a new building. The formal grounding will pave the way for system functionalities like reuse, modification, and consistency checks.
*2. A **methodology** for the three steps of process management: modeling, scheduling and monitoring.* To make the framework usable by SMEs without expensive training or acquiring additional competences, we will develop a methodology that is organized in three modules: *i) Modeling:* steps needed to orchestrate and further refine collaborative process models; *ii) Scheduling:* guidelines for the scheduling of the daily activities to be performed on-site; and *iii)* for the *Monitoring:* steps taken by the workers on-site in reporting on the current construction progress.
*3. An **integrated SW tool** that supports the activities of modeling, scheduling and monitoring.* The tool will be implemented as a web application and will be available as SaaS (Software as a Service). Additionally, we will release the code with the licence open source "Apache 2.0".

2.3 Activities

To achieve the objectives of COCkPiT, we have organized a series of activities in seven workpackages (WPs), two administrative and five technical.

WP 1 Project Management.
WP 2 Dissemination.
WP 3 Industry Engagement.
WP 4 Development of a Framework, Methodology and Tool for Process Modeling.
WP 5 Development of a Methodology and a Tool for Rolling Scheduling.
WP 6 Development of a Methodology and a Tool for Real-Time Monitoring.
WP 7 Knowledge Transfer and Validation.

The overall approach of technical WPs will be guided by the requirements of the industrial project partners, whose competences cover all the three construction phases (skeleton, envelope and interior construction). UniBZ will have a predominant role in project management, design and development of the *COCkPiT* methodologies and tools, and coordination of the working resources; Fraunhofer's main role will be the one of mediator and interface with the participating companies.

(WP 1) Project Management. The main objective of this WP is to ensure the scientific and administrative coordination of the project to: *i)* create the necessary conditions for the accomplishment of the project objectives; *ii)* supervise and support the technical and scientific work performed by the different WPs; *iii)* manage all administrative and financial issues; *iv)* ensure that deliverables are released on time; and *v)* take care of quality insurance for the actions undertaken by the project.

The role of management will be mainly assigned to the Project Leader (PL), with a tight collaboration with the team members. The PL will have the overall responsibility of the success of the project, for the achievement of the *COCkPiT*'s objectives and for monitoring the progress and managing emerging risks and issues. He will also take care of the hiring and recruiting.

The main areas in the project are IT, Industrial Engineering, and Construction Management. For each of them we respectively identified Prof. Nutt, Prof. Matt and Dott. Ing. Krause the *area leaders*. Their role will be to interface with the PL, in order to monitor the advancement of the project and promptly discover possible sources of delays or other obstacles. The area leaders will be supported in their work by three *area managers*, who will be responsible for the day-to-day management of the areas and for reporting on progress. These roles will be covered, respectively, by two research assistant professors at the faculties of Computer Science and Science and Technology and by Ing. Marcher from Fraunhofer. The area managers will organize weekly meetings among themselves. The area managers will meet monthly with the area leaders, which includes the PL, to report on the progress of the work. Additionally, area managers and area leaders will quarterly provide internal status report. For each WP we identified the main area in which it is being developed. The corresponding area leader will be responsible to ensure that the deadlines will be respected and to monitor the quality of the work done. To ensure coordination among all these parties, suitable tools will be set up, such as Trello for coordinating and planning the daily activities, Git as a version control system for the development, and Dropbox to share files.

An *Industrial Advisory Board* will be formed, with two representatives from each supporting company. Its role will be to provide the technical requirements for the methodology and the tools that will be developed in the project and to monitor their satisfaction.

Activities by partner:

A-UniBZ: Overall management and coordination among the team members.

A-Fh: Participation in the management and interface with the supporting companies.

(WP 2) Dissemination. With their dissemination activities, the parties involved in the project will ensure that the project findings are spread throughout the project lifetime and beyond. The specific objectives of this WP: *i)* Create and disseminate the project marketing material; *ii)* Present research papers at relevant conferences and in journals; *iii)* Organize public events.

Concretely, these objectives will be achieved by organizing press releases in social media (e.g., facebook, twitter, G+), specialized networks (e.g., LinkedIn, ResearchGate, Academia.edu), and other media (e.g., local newspapers, economic bulletins). We will set up a web site for a generic public, containing non-confidential information about the project and its advances, including deliverables and publications and information on the events organized within the project or in which we participate. All partners will aim at propagating the project results in high-quality peer-reviewed research publications, such as the conferences CAiSE, BPM, AAMAS, IJCAI, JAAMAS, IOEM, IGIL, and the journals J. of Automation in Construction, International J. in Construction Engineering and Management, J. of Industrial Engineering and Management. We will target the general public and especially entrepreneurs by participating in regional events such as the Long Night of Research, the Innovation Festival, the Start-Up Weekend, and cluster meetings organized by IDM Sudtirol-Alto Adige, and by getting involved in the South Tyrolean construction committee. For this kind of events, dissemination and promotional material will be produced (e.g. flyers, brochures, posters, demos). These activities will be supported by a *Dissemination Committee,* composed of representatives of the following institutions and professional associations of the Bolzano province: chamber of architects, chamber of engineers, construction committee, and construction cluster of IDM. Additionally, Prof. Baldoni and Prof. Baroglio from the University of Torino and Dr. Tautschnig fro the University of Innsbruck will be part of the committee. The members will spread the ideas and the content of the project within their professional networks.

In the last month of the project we will organize a *COCkPiT Workshop* to disseminate the achieved results. We will invite two speakers working in the field, who will describe the current situation in construction management and the environment they are working in. We will place the outcomes of COCkPiT in this picture and show the achievements and results of our approach.

Activities by partner:

A-UniBZ Publication and presentation of research papers; set up of the web site, management of the communication via social media and specialized networks, participation in research events open to the public, preparation of videos and demos for advertising purposes.

A-Fh Press releases in media, advertisement among the companies, advertisement among the Fhpeers and collaborators, preparation of flyers and advertising material, organization of the COCkPiT Workshop.

(WP 3) Industry Engagement. To give companies a central role in COCkPiT, the Industrial Advisory board (IA board) will be involved in different phases.

The aim of this WP is to understand from the companies that support the project their current practice of use and to collect real project scenarios. To this end, we foresee a first *technical kick-off meeting* of half a day with the IA board. During this meeting, we will first illustrate the approach we want to develop with the real case study of the hospital of Bolzano. This will ensure that all participants have the same understanding of the approach. As a second step, we will collect information on the companies' current practice of use in terms of management methodology and tools they are using. We foresee to buy the licences of (some of) these tools to better understand their use and possibly develop functionalities (e.g. export data in compatible format) to integrate our prototype with them.

At a second workshop of half a day, we will collect from the IA board a number of project scenarios in the context of civil engineering building and with different characteristics (e.g., industrial, commercial, residential construction scenarios). These scenarios will be used in the following WPs to define use cases and requirements and to test the tools that will be developed.

Activities by partner:

A-UniBZ Participation in the workshops, elaboration of the project scenarios and identification of the main challenges.

A-Fh Organization of the *workshops with companies*, preparation of the material, collection of project scenarios and practice of use.

(WP 4) Development of a Framework, Methodology and Tool for Process Modeling. In this work package we will develop the module for collaborative process modeling. This will be done with two main steps: *i)* the development of the conceptual underpinning and of the methodology to support this process modeling, and *ii)* the development of a software prototype to support it.

Framework and Methodology. The formal framework lays the basis not only for the modeling module, but also for the scheduling and monitoring modules, and the relations among the three of them. Our starting point will be the language developed in *build4future* for which a first formalization has been provided in the subsequent project MoMaPC (see [18]). In COCkPiT, we will extend the formalization to cover the three phases of skeleton, envelope and interior construction.

We will formalize the concept of construction areas as they are described in [10] but not yet formalized. We will introduce the concept of task and sub-task. The former will represent the main activities of the different companies on which they have to coordinate. Their definition will then be refined by specifying the sub-tasks composing them. Additionally, we will formalize the concept of *critical paths* for our language and design suitable shortest path algorithms to compute them. We will also formalize consistency checks in terms of satisfiability of the dependencies among the tasks and satisfiability of a process model given the quantities and kinds of resources that will be available on-site. To this aim we will apply constraint satisfaction and model checking techniques [15].

The methodology to support the collaborative process modeling will be defined so as to meet the requirements collected during the workshops with the IA board and subsequent interaction with the companies. We expect the methodology to define the following steps: *i)* Identification of the construction areas within the building; *ii)* Definition of tasks, their localization in the identified construction areas, productivity, and needed resources; *iii)* Identification of the dependencies occurring among the tasks; *iv)* Specification of the sub-tasks defining the tasks; *v)* for each sub-task, definition of: locations, resources, expected progress. The resulting methodology will be presented to the IA board during a half-day workshop.

Development of a supporting tool. As a first step for the development of the tool we will collect the functional requirements and the main functionalities the prototype will support, such as the possibility to manage more than one project and associate different rights to different users; to retrieve the tasks from an ontology and so on. We will consider additional requirements for the use of the tool with touch devices. For example, we will support the input, which is difficult without a keyboard, with menus or drop-down lists. We will test the prototype on a digital board currently available at the Faculty of Science and Technology.

Our starting point will be the demonstrator we developed in [24], which will be adapted and extended to account for the novelties introduced in the formal framework. It will represent: *i)* tasks, sub-tasks and dependencies among them; *ii)* shared resources; *iii)* the different kinds of dependencies we defined in [18]; *iv)* different construction area representation for the different construction phases. We will develop a Web application using standard technologies such as Java servlets, mySQL database, and the Hibernate framework. For the client side we will design a user-friendly graphical interface according to the Human Computing Interaction principles [21]. Additionally, we will implement analysis functionalities such as critical path algorithms and consistency checks.

During the development, the prototype will be tested by simulating the case studies identified previously. An almost complete version will be presented to the IA board at a dedicated workshop.

Activities by partner:

A-UniBZ Definition of use cases, development of framework and methodology, functional requirement analysis for the tool, design of the SW prototype;

implementation and testing.

A-Fh Definition of use cases, identification of industry requirements, development of the methodology with the industries, collection of customer requirements for the tool, workshop organisation, support for the testing of the tool.

(WP 5) Development of a Methodology and a Tool for Short-Term Capacitive Scheduling. For the development of the methodology we will collect a number of use cases for short-term capacitive scheduling starting from the project scenarios identified in WP 1 and by organizing two workshops with the IA board. From these, we will extract the requirements.

We expect that scheduling will be driven by three main factors, namely *i)* the actual progress of the work on-site; *ii)* the available resources; and *iii)* the building locations. Based on these criteria, the tasks that can be scheduled in a certain period are those not completed yet, foreseen in the selected location and that can be performed given the available resources. Accordingly, we expect the methodology to foresee the following main steps: *i)* identification of the time frame (weekly or daily) and of the construction phase (skeleton, envelop or interior); *ii)* identification of the resources available on-site; *iii)* selection of a location of the building where to schedule some task; *iv)* select the tasks to be executed and assign the needed resources. The methodology will be presented to the IA board during one workshop of half a day.

We will develop a software prototype to support the short-term capacity scheduling. Our starting point will be the demonstrator developed in the MoMaPC project. In *COCkPiT* we will extend it targeting the following main aims: *i)* Consider all the construction phases, beside the envelope construction currently implemented. *ii)* Integrate the scheduling with the monitoring and the modeling module, currently not implemented in the demonstrator. This entails checking the constraints coming from the process model, and use the actual progress of a task to perform a reliable schedule. To check that the constraints are satisfied by the current schedule we plan to adopt model checking techniques [15] as described in [18]. *iii)* Implement functionalities that support an analysis of the overall trend of the construction process. For instance, we will implement forecast functionalities for the expected time to completion of a task or for the achievement of a milestone. Additionally, the user will be able to specify a number of objectives to optimize (e.g. minimize the overall time, and maximize the usage of resources) and the system will suggest possible schedules and predict the budget. To this aim we will formulate scheduling as a multi-objective optimization problem. *iv)* Export functionalities as excel spreadsheets, BIM–4D and representation of the current schedule as a *flowline chart* [16].

During its development, the prototype will be tested on the case studies. Additionally, it will be evaluated with the IA board during a workshop of half a day.

Activities by partner:

A-UniBZ definition of use cases, development of the methodology, functional requirements analysis, design of the SW prototype, implementation and testing.

A-Fh organization of workshops with the IA board, definition of use cases, identification of industry requirements, development of the methodology with the partner companies, support to the testing of the tool;

(WP 6) Development of a Methodology and a Tool for Real-Time Monitoring. The monitoring of the advancement of the work on-site will be based on the concept of pitch, which represents the amount of work that can be performed by a crew of workers in a specific time interval. Accordingly, we will define a pitch-based methodology to track the progress on-site. In particular, the methodology will define guidelines for workers on-site to report on the status of the tasks on-site (e.g., work completed, in progress, identified problems). The methodology will define how to measure in detail the construction progress. This is particularly important in the interior construction phase, because different trades have to work at the same time in the same building. Therefore, a detailed measurement of the construction progress would allow one to increase the parallelism and, therefore, to reduce the overall lead time. Additionally, the methodology will require a distribution of the responsibilities in the execution of a construction process. The responsible will thus be in charge of reporting to the superior in case of unforeseen events or delays. To this aim, in the context of the collaboration with the University of Torino, we plan to investigate the adoption of a *commitment-based* specification associated to the tasks to clearly identify the responsibilities [6]. We also plan to investigate the distinction between accountability and responsibility.

The methodology will be presented to the IA board in the context of a half day workshop.

Concerning the development of the tool, we expect it to be tightly connected to the prototype for the scheduling. Therefore, for the software design we will start from the conceptual model we will develop for the scheduling module. Also for the design of the user interface, we will use as starting point the one developed for the scheduling, and we will then adapt it to the different requirements. The tool will support the usage of RFID or QR codes on-site to identify more easily locations and resources on-site.

The testing will be done during the development on the identified use cases, and a first version of the prototype will be presented to the IA board in the context of a half day workshop.

Activities by partner:

A-UniBZ Definition of use cases, development of a methodology, functional requirements analysis, design of the SW prototype, implementation and testing.

A-Fh Definition of use cases, industries requirements identification, workshop and development of the methodology with the industries, collection of customer requirements for the tool, support to the testing of the tool.

(WP 7) Knowledge Transfer and Validation. This work package concerns the validation of the prototype and of the developed methodologies for the three modules (modeling, scheduling and monitoring). It will be carried out on pilot projects supplied by the companies that are part of the IA board. For the validation we foresee two main phases. The first one will concern the process modeling and will be done at the end of WP 4. In the context of two workshops of half a day, the companies will be educated on the developed framework and methodology, by applying them to one of the pilot projects. The process will be modelled in a collaborative way, with the support of the developed tool.

The second phase will concern the scheduling and monitoring modules. We will configure the developed prototype for the pilot projects and will educate the companies on the developed methodologies and the use of the prototype. The companies will be supported in weekly meetings for using the SW prototype in the pilot projects.

Activities by partner:

A-UniBZ Validation with the companies.

A-Fh Setting-up the environment for the validation, coaching to the industries, validation with the industries.

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