A MODEL-BASED PRODUCTION PLANNING AND CONTROL METHOD SUPPORTING DELIVERY OF CAST IN PLACE CONCRETE

Håkan Norberg, MSc, PhD Candidate
Department of Civil, Mining and Environmental Engineering, Luleå University of Technology, Sweden
hakan.norberg@ltu.se, http://construction.project.ltu.se/~ebygg

Rogier Jongeling, Associate Professor
Department of Civil, Mining and Environmental Engineering, Luleå University of Technology, Sweden
rogier.jongeling@ltu.se, http://construction.project.ltu.se/~ebygg

SUMMARY: *This paper combines model-based design and construction techniques with principles from location based planning methods. Both concepts are applied in a practical study in which a model-based method is developed for the planning and control of cast in place concrete deliveries to the building site. The overall aim of this paper is to show a method that can be used to make the planning and control of the delivery process for cast in place concrete more efficient. The paper shows examples of changes in the way the concrete delivery process is handled by different actors. Using model-based working methods allow users to have better control of how for example material properties, such as concrete drying time, affect the planning and control of the delivery process. The paper first provides a background of the research including a description of the case study project. This section is followed by a description of the various methods and systems used in the case study. The application of the method is discussed, based on interviews with both a ready-mixed concrete supplier and a contractor that took part in the case study. The paper is concluded with suggestions for how the method can be further developed and improved to support the scheduling and control of cast in place concrete delivery.*

KEYWORDS: *4D modelling, Location based scheduling, Cast in place concrete, Concrete desiccation*

1. INTRODUCTION

Productivity in the construction sector has not increased with the same pace as the manufacturing industry during the last decades. One reason is the fact that the manufacturing industry has adopted a lean production philosophy combined with model-based product development. Model-based product development has enabled manufacturers to have a better control and understanding of the information generated and required for the product development and production process. Inspired by the manufacturing industry, the construction industry has started to adapt model-based working methods. Model-based techniques are in construction currently mainly referred to as building information modelling (BIM).

The construction industry wants a higher degree of industrialisation, which often is interpreted as prefabrication of components in factories and assembly on site. Industrial construction is not limited or synonymous to prefabrication but can also be applied to cast in place concrete construction; a process in which most of the work is carried out on the building site.

In cast-in-place concrete construction it is important to use concrete qualities with desiccation durations shorter than the time between pouring the concrete and the floor covering activity to prevent future moisture in the structure. These desiccation durations can be calculated which often results in different concrete qualities at different parts of the concrete structure. Model-based working methods allow users to have control of where and when these concrete qualities will be used.

To work productively in on-site production it is important to create a continuous flow of available recourses. This is achieved by creating conditions in the planning and preparation phase to prevent discontinuity in production. There are a couple of techniques available, such as location based scheduling, 4D modelling and the Last Planner theory, which can be used to achieve that continuity. But using these techniques does not automatically solve the problem. The process of working with them and the information exchange must be well-defined. This paper is a first attempt to define such a process applied to cast-in-place concrete construction.

2. THEORY

2.1 Building information modelling

Building Information Modelling (BIM) is the process of creating an object-oriented 3D-CAD model, which also is referred to as BIM. The verb BIM is process oriented about how to act when creating the noun BIM which is the result of the process. The noun BIM is a static representation of a building that contains multidisciplinary data that defines the building from the point of view of more than one discipline. A BIM also includes relationships and inheritances for each building component. A 3D model that only defines a single view of a building, for example a structural engineers view, is not a BIM. BIM is also a process about systematically creating, storing and using model-based information. This definition implies that a 3D model is not automatically a BIM, it has to be object-oriented and contain information about the construction process and the product. A 3D model created just to visualize the graphic of building components are not per definition automatically a BIM. But a BIM can be the origin to a 3D visualization by adding textures etcetera. (Bazjanac 2004)

A BIM project is a project in which information exchange mainly is performed between BIM software and different actors, i.e. there are different extents of BIM projects depending on in which way information is exchanged between different actors. For example, many actors are internally working with BIM software to speed up their process but when they deliver their information to other project participants they exchange information in a traditional way. There are a number of different reasons for this practice, which are of practical, strategical and technical nature. In many cases there are no explicit requirements to deliver a BIM and actors are required to submit design documentation in a traditional way. Some actors do not trust the technology or are unsure about the legal status of a BIM and are therefore reluctant to share their model. In other cases information is not shared due to technical difficulties related for example to different data formats. These are just a number of examples of obstacles for sharing of model-based information. (Jongeling 2008)

2.2 Location based planning methods

The scheduling work in a construction project commonly consists of decomposing the project into manageable parts. Activities are defined to which a time frame is assigned, as well as resources such as equipment, materials and labour required to perform construction work. Proper scheduling eliminates bottlenecks and facilitates the supply of materials. Poor scheduling often results in waste, such as waiting time on site. The challenge in scheduling is to create enough time-space buffers between activities without making the buffers too big which results in poor economy of the project (Jongeling 2006). There are two main methodologies for scheduling: activity based scheduling and location based scheduling. These methodologies in turn have many different techniques (Kenley 2004).

In construction projects the activity based scheduling method is the most used and often represented as a Gantt chart (Seppänen and Kenley 2005). The method is built on the assumption that activities are discrete events that are carried out on a predestined discrete location. The method relies on the Critical Path method, in which activities are identified that set the duration and pace of the entire project. If these activities can be identified and managed properly, the project can be controlled. Non-critical activities can be rescheduled without affecting the whole project. Gantt charts are often discipline oriented and do not consider the spatial layout of the project nor the spatial interaction between trades. (Jongeling 2006)

A method which better supports the fact that construction projects are dependent of the spatial layout is the location based scheduling technique. This is not a new technique but due to the strong tradition of activity based scheduling the practical use in construction has been limited (Jongeling 2006). According to Mendez and Heineck (1998) the main concept of location based scheduling is the work continuity of the labour teams over the construction units. This technique is suitable for repetitive projects like residential buildings etcetera. The activities are represented by lines in a diagram going through the locations of the project. The spatial divisions are defined by the work breakdown structure (WBS) of the project.

4D modelling integrates schedule information to 3D models. This makes it possible to display the planned schedule in a so-called 4D environment. 4D tools can output a movie of the linked schedule so that all participants in a project can understand the construction plan more realistically or show potential conflicts before they appear on site. Planners can also practise what-if scenarios to compare possible sequences. 4D-models are typically used graphically. Attempts are made however to incorporate other construction aspects in the 4D model, such as resource management, cost assessment and supply of materials to and within the construction site. (Wang et al. 2004)

3. CASE STUDY

The case study project consists of a new residential area in the south of Sweden. The area will include about three hundred new residences consisting of both detached houses and row houses. The project is divided in several parts and each part consists of a number of phases. This first part, shown in FIG. 1, consists of forty-seven residences divided in four phases.

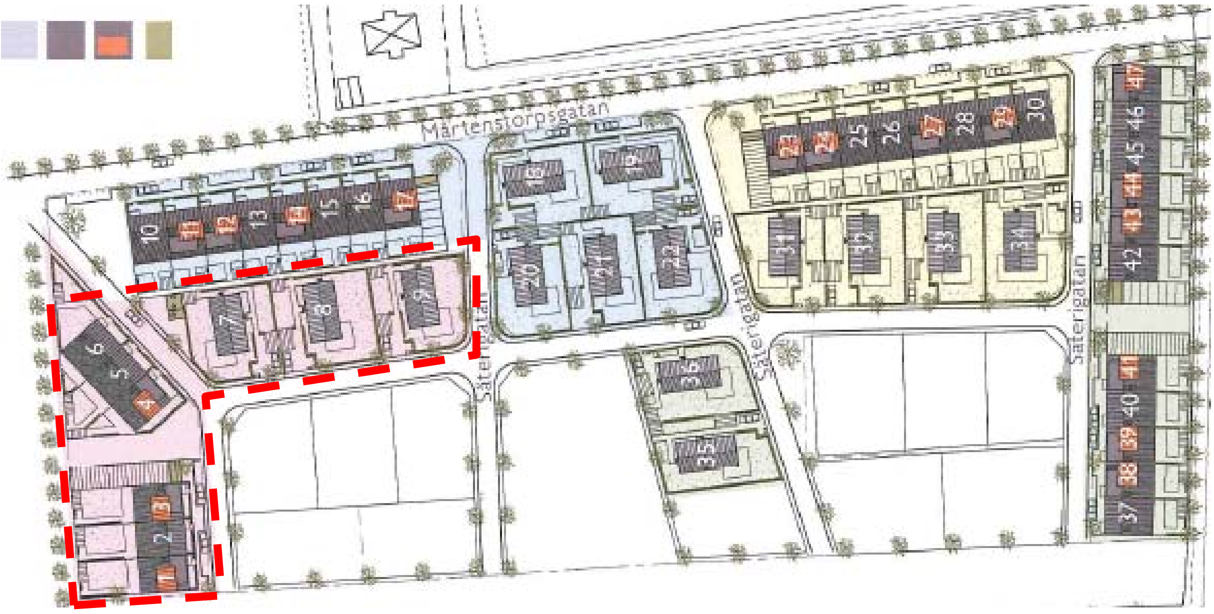

FIG. 1: Site layout of the case study project. The first phase is marked with a dashed line.

The ground floor and the floor structure in the row houses consist of cast-in-place concrete slabs. All other bearing structures are prefabricated components. Oak parquet and clinker are used as floor material in all apartments. A concrete supplier helps the contractor to choose the most suitable concrete quality for each casting sequence to prevent future moisture in the building, with special consideration to the flooring material.

3.1 Application in case study project

We used the case study to test our theories and methods which were presented to the main contractor and the concrete supplier and resulted in feedback. This part describes the process step by step

3.1.1 Building information modelling

The project was originally designed and modelled in 2D. We therefore had to create a 3D building information model including necessary components to simulate the activities in the schedule. Most of the work was concentrated on the concrete slabs which had to be divided into several parts depending on the type of room (living room, WC, etc.) and the type of flooring material that was going to be used. The thicknesses of the ground floors were also varying depending on the haunches. Attributes were assigned to all slabs, such as volume, area, etc, to allow for quantity take offs. Other building components that were modelled in the 3D building information model was a) steel columns and beams; b) prefabricated external walls in the detached houses; c) prefabricated bearing walls in the row houses (gables and dividing walls); d) prefabricated slabs for the balconies; and e) ground floors in the storages.

To be able to simulate activities in the schedule not represented by modelled components we created 3D spaces for each apartment on each floor and in each detached house. The spaces were given a degree of transparency to allow the user to see the building components inside them. Some of the surroundings, such as roads and trees, were also modelled to define the site context.

3.1.2 Concrete quality calculations

Calculations to determine the required concrete qualities of the slabs were made by the concrete supplier in consultation with the contractor of the project. Most input data could be found in the schedule, blueprints and in descriptions of the project, but some information was supplied directly by the site manager. For example, will the slab be covered after the concrete pouring and if so when will the slab be covered and uncovered, will underfloor heating be used and if so what type of underfloor heating and when will it be used?

The results from the calculations for the first phase (of in total four phases) are presented in TABLE 1 below. The different slabs used in the project are shown with an abbreviation such as P55 (Concrete ground slab with a thickness of 55 millimetres). The proposed concrete quality is either a standard C25/35 or a special concrete with shorter desiccation duration found by the concrete supplier (TorkBiX). The desiccation durations for proposed concrete quality can also be found in the table.

TABLE 1: Concrete quality results from desiccation calculations.

Phase	Building	Slab	Concrete quality	Desiccation duration (days)
1	Row house F & E	P55	TorkBi3	84
		P300	TorkBi5	84
		P100	C25/30	84
		B250	TorkBi5	70
	House 12-14	P55	TorkBi1	35
		P300	TorkBi5	35
		P100	TorkBi5	35

3.1.3 Location based desiccation simulations

After having determined the concrete qualities we performed a location based visualization of the desiccation durations of the proposed concrete qualities. The project was not originally planned with location based scheduling technique. The activities belonging to the desiccation durations were therefore manually converted from the Gantt chart into a location based scheduling software, see FIG. 2. First the pouring concrete and the floor covering activities were converted (represented by the green, blue and cyan lines). These activities are not intelligent, i.e. they have no information about quantities and the amount of workers, but that is not considered necessary in this case. Information needed is start, stop and where the activities are going to be carried out. To simulate the desiccation durations the pouring concrete activity was copied and moved in accordance to the result from the concrete quality calculations. For phase 1 the activity had to be copied three times because of the three different calculated desiccation durations (84, 70 and 35 days).

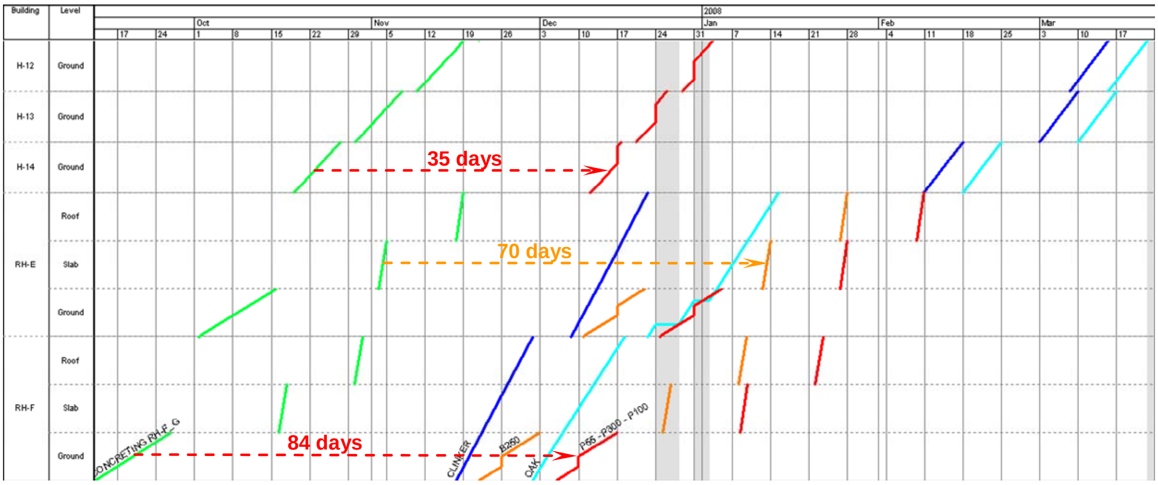

FIG. 2: Location based desiccation simulation for phase 1.

The location based schedule shows that choosing the concrete qualities recommended in the calculations will probably cause problems with moisture in the row houses. The calculated desiccation durations of seventy respectively eighty-four days will lead to moisture built in by the floor covering activities. This is shown by the desiccation durations which are behind the floor covering activities in time. There are four possible solutions to this problem:

1. Change the concrete quality to a concrete type with shorter desiccation duration and make a new calculation. This will affect the production cost because of the more expensive concrete quality.
2. Reschedule the floor covering activities. This will probably cause a delay of the whole project which often is expensive.
3. Change or add methods that affect the calculation result. This can be done by covering the slab after pouring the concrete or by using underfloor heating in the slabs.
4. Reschedule activities that affect the calculation results. For example try to build the roof earlier or install windows earlier to create an indoor climatic condition that will speed up the desiccation.

The best solution is probably to combine all these control actions.

3.1.4 4D simulations

To be able to perform 4D simulations the building information model and the project master schedule were imported to a 4D viewer. Due to the large area of the site the site manager wanted to use the 4D model to visualize where the different crews should be at a specific moment. The 4D model was prepared with different activity types using a unique colour to represent crews working with concrete, wood, forging operations, bearing structure, scaffolding, roof works, sheet metal, floor covering, painting, electricity, heating and sanitation and finally ventilation. The activities in the schedule were then linked to the building components and the spaces in the model. Before the staff on site had learned using the 4D viewer, snapshots were taken for each week of the project and printed out for use on-site. This gave the staff the opportunity, in a very simple way, to get an overview of the planned production and where different crews should be working at specific times. Later on, after a short course about navigating and using the viewer to communicate the schedule, the staff could start using the model by themselves.

The model was also used to simulate the desiccation of the concrete slabs. For this purpose the location based schedule was imported to the 4D viewer including information about times for the pouring concrete activities, the floor covering activities and the durations of the concrete desiccation. These activities were subsequently linked to the slab objects in the 4D model.

3.1.5 Model-based quantity take off

When the CAD objects were imported to the viewer the associated object attributes were also included as shown in FIG. 3. This means that it is possible to read the attributes when pointing at an object in the model allowing ordering concrete directly from the model.

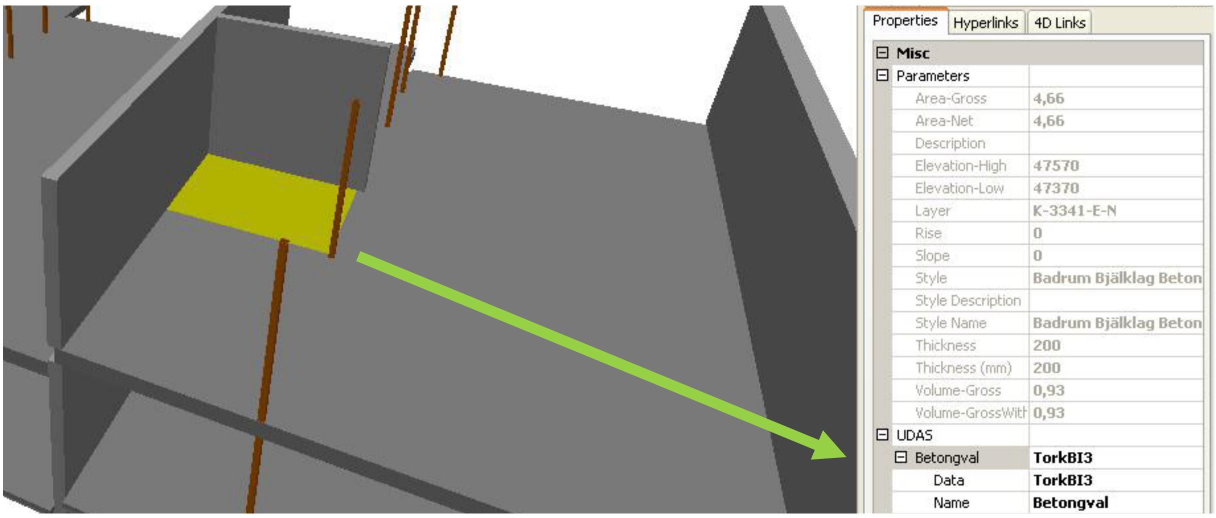

FIG. 3: A selected object containing data about the concrete quality and its volume.

To create these orders information about the calculated concrete quality is required. The concrete quality was added in the viewer by adding so-called UDAs (User Defined Attribute) with the concrete quality as data. This data was added to all cast-in-place concrete objects in the 4D model. FIG. 3 is showing an object, representing a cast-in-place slab, with information about recommended concrete quality and the volume that must be supplied. Furthermore it is possible to get the information about the area, thickness, classification and the fact that the object is a slab in the bathroom of the apartment.

Knowing this information it is possible to quick and easy make quantity take offs directly from the 4D model without any CAD tool, external estimating tool or Excel sheets. This is done by selecting optional objects, for example the slabs which are going to be poured in the next casting sequence, and selecting a reporting tool to group objects, including their attributes, according to user-defined sets. These reports were used as requests to inform the concrete supplier about the content in scheduled deliveries. The reports were instrumental in reducing the risks for the delivery of incorrect concrete quality and volume.

3.2 Observations from the case study: advantages and shortcomings

The first concrete quality calculation resulted in a quality with too long desiccation duration due to poor communication between the calculator and the site manager i.e. the calculator got wrong input to perform the calculations. The desiccation durations were far behind from the start of the floor covering activities. This part of the process must be better defined to minimize the lack of information. The calculation error was not detected during the time the project team solely used a Gantt chart. However, the error was identified when the desiccation durations were visualized in the location based schedule.

The master schedule is preferably created in location based scheduling software, since the method supports scheduling and controlling work flow on site. The location based schedule also facilitates the flow of information in the process, i.e. the desiccation duration can be imported directly into the master schedule without converting the activities from a Gantt chart.

In the beginning of the project we planned to use 4D modelling out on the construction site to support the daily work. However, the use of the 4D-model was limited due to insufficient training and a too complex user interface of the used software. The project participants suggested simplifying the 4D application to make the work quicker and easier. They also pointed out that the model must be well prepared with pre-set viewpoints etcetera. The substance of their comments was about making the application and the work process so easy that it will not cause any more work than they do today. Since we did the linking work between the schedule and the modelled objects by ourselves (the contractor did not join us in the process) information lacked to link all activities to the right objects. This affected the model and thereby the possibility to derive benefits from the 4D model. Simulating the desiccation durations was not tested on site.

The contractor was very positive to the model-based quantity take off for concrete delivery orders and considered this function useful in several ways. Since the model was created from original 2D drawings by a third party some errors occurred. For example, some of the slabs had wrong thickness and the haunches had incorrect geometry. Due to the poor quality of the building information model this function could not be applied in practice. The risk that the model-based reports would contain wrong information about concrete volumes was considered too high. One suggestion was to add a factor lower than one to the volumes to decrease the order of concrete regarding to sanitation pipes inside slabs etcetera. Adding such a factor might incur risk because of the uncertainty when setting that factor. It can be set based on historical data of delivered concrete volumes to different kind of slabs but that database will probably take long time to build up to be safe enough. Another possibility is to model all pipes and ducts etcetera in 3D and subtract its volume from the concrete order. Reduction of the concrete volume depending of reinforcement can be calculated by the information from the recipes including number of kilogram per square meter concrete slab. However, this factor or subtracting method must be done by the contractor of the project.

The bottleneck in this process is the fact that the concrete quality calculations are static. A schedule should be dynamic with the opportunity to be rescheduled when ever it needs. If the information in the schedule were direct linked to the input in the calculation it would be possible to manage the dynamic schedules. Creating the master schedule as a Gantt chart makes the information exchange between the master schedule and the location based desiccation visualization software disparagingly. When using Gantt charts for project planning it can be better to skip the location based desiccation visualization and only use the 4D simulation to control the desiccation durations. This would create a better flow of the process.

According to Stewart et al. (2002) and Larsson (2003) this type of IT/IS projects need to be well prepared by a step-by-step implementation plan and with well defined visions and action plans. This project missed some of the contents in these plans. To start with, the project did not have a review committee and a strategic implementation plan was not used. Some kind of action plan was developed but it was not dynamic with new actions through the project. Visions were only created in each of the participant's minds but were not printed out to share with all in the project and to strive for the goal. The skills of the participants in the applications were not good enough because too less training. There was no need to implement a reward and recognition system because all participant were enough motivated after a demonstration of the benefits in using these tools. The biggest problem in this project was the lack of human resources. As a Ph.D. student it was not possible to serve the participant with as much support as they needed. This was depending both in lack of time and the distance between the office and the case study project.

4. PROPOSED PROCESS AND IMPLEMENTATION

4.1 Process

This section presents a proposed process method for the process of working with model- and location-based techniques and aims to define relations between these techniques. The process method is based on the results from the case study project and from feedback delivered by the contractor of the project and the concrete supplier.

The proposed process in FIG. 4 is based on the method described in chapter 3.1. The process consists of in total nine main steps. The first step starts with creating a building information model of the project. The information in a process like this should be based on a building information model already created in the design phase of the project. The rules of creating the geometry and the including information which must be delivered should be well defined in a CAD manual. Sending 2D drawings to a third party involves one more step in the process which makes the risk for errors bigger. But in the implementation phase of working according to this process the third party building information model can be a good alternative to speed up the implementation. Depending on the level of detail of the building information model it is possible to create a preliminary model-based quantity take off. These quantity take offs are not product specific (i.e. only the volume is known, but not the concrete quality). These quantity take offs can give the concrete supplier a forecast about how much concrete will be ordered in the near future. Using model-based quantity take off in the early phase even shortens the information flow, i.e. exact quantities can be exported directly from the model instead of blueprints, ruler and lots of measuring inaccuracies.

The second step of the process starts with the creation of a master schedule of the project. Considering work flow management the schedule is preferably created using location based scheduling techniques. This schedule includes information about when and where activities like pouring concrete, roof works, installation of windows and wall covering are planned to start. In step three the information from the building information model and the master schedule are imported to the 4D viewer. The 3D objects are linked to the activities in the schedule and a macro 4D simulation is performed. If the simulation is approved by the site manager the next step in the process, concrete quality calculations, can start. Otherwise the project has to be rescheduled. To minimize the information exchange, or the lack of information, the 4D linking should be performed by the site manager but in the implementation phase this work can be done by an external 4D modeller. When working in that way it is important to get a close collaboration between the 4D modeller and the site manager to minimize the risks of loosing information. The site manager has to define exactly how the 4D model should be delivered to the site. This information should be changed in a first meeting where the 4D modeller presents the 3D geometry in the model and where the site manager approve, or disapprove, the model if it meets the requirements or not. In the following time the 4D modeller and the site manager should continuously have information exchange about the process to prevent lack of information.

To start the calculations information about pouring technique etcetera must be accessed by the site manager and the planned schedule. The result from the calculations is a proposed concrete quality and its desiccation duration. This calculation is done for every single slab. In step five the desiccation durations are visualized against the planned activities in a location based schedule. If the project schedule is available as a Gantt chart this schedule must be transformed into a location based schedule before the visualization can be done. If the visualization satisfy the site manager, according to planned floor covering activity versus calculated durations of the concrete desiccation, the process moves on to step six. If the visualization in the location based schedule shows that the desiccation durations are behind the start of the floor covering activities the concrete qualities must be recalculated.

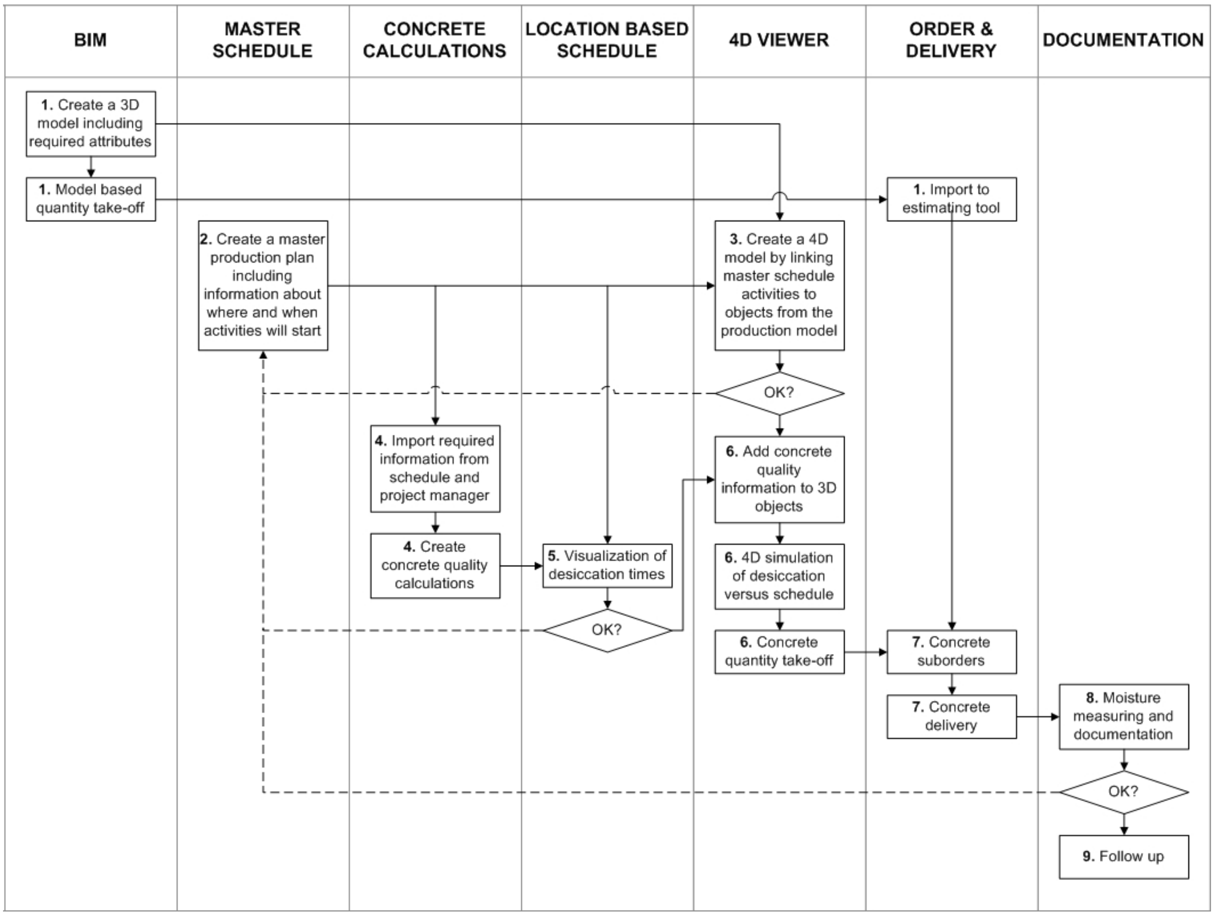

FIG. 4: A proposed process method to support cast in place concrete construction using model- and location-based techniques.

Step six consists of adding the concrete quality information to the slab objects, perform a 4D simulation of the desiccation durations versus the planned schedule and finally perform model-based quantity take offs of the concrete directly from the 4D viewer. Adding the concrete quality information to the 3D objects directly in the viewer facilitates the process flow. Since this information is known late in the process the process flow would stop if this information has to be put into the original building information model with following updates of the objects in the viewer. Order and delivery of the calculated concrete qualities are made in step number seven. In step eight, just before the floor covering activity starts, moisture measuring and documentation are done to prevent that moisture will be built-in the structure. If there still is moisture in the structure the floor covering and underlying activities must be rescheduled, otherwise the process is completed with a follow up of the process.

4.2 Implementation

A process model by its own is not a guarantee to succeed in real practise but what also is required is a detailed implementation strategy. There is a lot of various implementation strategies in the industry but in this paper we will use only two of them as examples. The first one is as step-by-step methodology by Stewart et al. (2002) presenting a strategic IT/IS implementation strategy. The second one presents five necessary components to implementing a Six Sigma culture by Larsson (2003). These implementation methods may not be fully applicable in this particular case but it gives an overview of important components when implementing new techniques and methods.

The methodology presented by Stewart et al. (2002) consists of six steps which will be described below. The implementation is performed by a cross functional team of staff members, the IT/IS Review Committee (RC), which goal is to achieve corporate objectives. In the first step SWOT (Strengths, Weaknesses, Opportunities and Threats) factors are identified to define the way the organisation is managed. By collating these factors the organisation can undertake an analysis of them in the second step, the SWOT analysis. This step is used to provide a good basis for the implementation strategy formulation. The third step is to develop a diffusion strategy and is done by an analysis of the information from the previous steps. This results in recommendations which in turn must be reviewed by all that will be affected of the proposed IT/IS system. The fourth step includes translating the recommendations into a more detailed operational strategy. In step five an implementation strategy or 'action plan' is developed which is the most detailed component of the strategic IT/IS implementation framework. This starts with the definition of action plans which includes an inventory of actions for implementation, a study of implementation procedures and action prioritisation with reference to strategic importance. When elaborating the action plans each action element must be studied concerning objectives, work breakdown structures, anticipated results, etc. The time and cost dimension must also be investigated, such as constraints, precedence, control points, purchase costs, development costs and maintenance costs. At the end of the elaboration phase, the human recourse issues (training, support, etc.) and the IT/IS management and coordination structure are analysed. Step five ends by reducing the risk factors or weaknesses in the strategic planning process. The five mentioned steps above should be supported by a monitor plan which is the sixth and last step in the implementation process. A continual performance monitoring should be implemented over the life cycle of the implemented process.

According to Larsson (2003) five components are required to establish a Six Sigma culture which is a quality tool to reduce variances in production. The components are (1) Vision; (2) Skills; (3) Incentive; (4) Resources and (5) Action plan. These components are not only important for implementing a Six Sigma culture but also for implementing all kinds of changes. Establishing a *Vision* sets the framework for the mission, objectives and strategies. This provides everyone with a clear view of what and how it is to be accomplished. Implementation without a vision will only lead to confusion. *Skills* are achieved through training. Without skills there will be no change, it will result in anxiety. Working for change with labours with no *incentives* will only lead to a gradual change. Motivation can be reached via different kinds of ways, i.e. tying bonuses to achieved goals or via a reward and recognition system. *Resources* in the form of continuous improvement teams need to be provided at least one hour a week for team meetings. People will need to be trained, teams will need to be facilitated and managers will need to be coached. Excluding this type of resources in the implementation phase will result in frustration in the teams. Divisions, departments, and work units are required to generate *Action Plans*. This is living documents which means that as action are completed, they are removed from the action plan and new action items need to be added. These action plans are reviewed on how well each entity is doing on completing their action plan. Implementation fails to start if action plans are not created.

5. CONCLUSION

Working according to the proposed process facilitates users to increase the productivity of the cast-in-place concrete production as a result of better support for work-flow and information management. The method is aimed at collaborating and sharing information in an efficient way. Techniques used in the proposed method are not limited to cast in place concrete construction and have a potential to improve the construction process for other types of construction work.

The method corresponds to location based planning methods. The well structured and well-defined process decreases waste as a result of poor information handling, which in turn create more value in the project. In addition, the application of model-based methods also facilitates the information exchange between different stake holders. Creating a 4D model based on the information from the BIM makes the information more accessible to the site manager which increases the possibility to manage and control the production in a more efficient way. The chances that the right material will be delivered in right time by using the information in the 4D model to order materials are higher compared to a traditional practice which in the long run decreases the construction costs. This case study shows the advantage of using model-based methods to cast-in-place concrete structures, i.e. not only to prefabricated components.

Seeing this case study as an attempt to implement the proposed process it can be concluded as failure but we think that this case study should be seen as a first study in the implementation process. From this paper it is possible to evaluate a vision that all can agree on and from there start with the step-by-step implementation methodology. The action plan created from that methodology should be well followed up with completed actions but also with necessary actions to be able to continue with the implementation. A cornerstone in implementing this IT/IS project is to add necessary human resources to support the participants.

Implementing a process like this takes time and questions will arise with a technical, methodological and organisation nature. New roles will for example appear which do not exist in traditional project planning. We believe these obstacles will gradually vanish when the different actors have experienced the benefits of sharing model-based information.

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