TEACHING CONSTRUCTION PROJECT PLANNING WITH BIM SUPPORT: UNRAVELING THE BLACK-BOX

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ABSTRACT

The use of Building Information (BI) models in construction project planning courses allows educators to design project based courses that rely on real world cases and, at the same time, enable students to integrate different project planning methods, integrate change management tasks, and optimize project plans (Peterson et al. 2011). However, such courses usually rely on the use of commercial BIM software products. These products tend to black-box the underlying building information models and building information model query functionality behind advanced user interface functions. This has the effect that students learn how to use the software to plan projects, but do not gain knowledge about the structure and technical use of the software's underlying information models. In the end, there is a high likelihood that students will not be able to internalize general applicable BI modeling and management concepts and only learn how to use software. This paper argues that the introduction of state of the art BI model servers allows to teach advanced project planning methods while students, at the same time, will gain an in depth understanding of how BI models are structured and can be queried. We provide first illustrative evidence for our argument by describing a Master course during which students had to use an IFC BIM server system to store their BI models, query these BI models using the JAVA programming language, and using the queried and aggregated BI data to generate, change, and optimize project plans using advanced project planning techniques. By systematically analyzing the results students achieved during the class, the paper shows that students were able to develop knowledge about sophisticated BI integrated project planning methods, while they at the same time gained in depth understanding about BI modeling and management techniques.

Keywords: building information modeling, project management, IFC, education, cost estimating, scheduling

1. INTRODUCTION

As construction planning practice moves more and more to the use of Building Information Models (BIM), educating students about model-based and integrated project planning practice becomes more and more important. So far, however, many universities struggle with incorporating BIM based project management contents in their curricula. The argument against the use of BIM is often that the existing BIM software black-boxes the underlying logic of integrated project planning which will hinder students to understand this logic conceptually. Others argue that the introduction of BIM in project management classes can also offer benefits (Peterson et al. 2011). So was it shown that the introduction of BIM actually supports the true teaching of cost-time-scope integrated project management concepts. Further was argued that BIM allowed students to understand the complex interrelations between cost, time, and scope in project plans based upon real world case projects.

This paper contributes to this previous work by reporting on the outcomes of an integrated project management class that was taught with BIM support, but did not rely on existing commercial software. On contrary, during the class that this paper describes students had to program their own integrated project planning solution using a combination of low-level tools, i.e. an ifc based BIM server, the JAVA programming language, and a spreadsheet application. The outcomes from the class show that it is feasible that students develop their own integrated and model-based project planning solution, while at the same time, they are able to experiment with generating integrated project plans for real-scale case projects. As a result, the underlying project management

concepts are no longer black boxed by software applications and students are truly able to learn model based project management concepts beyond the simple application of existing software tools.

The paper is structured as follows: It starts with a short theoretical introduction about the importance of project based teaching of integrated project planning and about the feasibility to do so using existing BIM tools. The paper then introduces and describes the project based class that illustrates that it is feasible to teach integrated project planning classes during which students develop their own integrative and model-based solutions without relying on commercial BIM software. The paper concludes with a short discussion of the outcomes of this class.

2. TEACHING PROJECT MANAGEMENT WITH BIM

During project planning, construction managers need to carefully balance the scope, time, and cost of the project (Clough 2000, Winch 2002). Plans and specifications represent the project scope. Scope defines the work that is required to complete the project successfully. Based on the scope, project planners estimate the time it takes to carry out the work and the costs of doing so. In practice, whether practitioners are aware of it or not, project planning and execution is an effort to integrate these three parts. The plans, specifications, quantity takeoff, schedule, and estimate document the scope, time, and cost. Project managers constantly translate information from these documents to understand how the scope, time, and cost relate. Additionally, construction projects operate in drifting environments (Kreiner 1995) and, thus, changes have to be integrated frequently which additionally heightens the complexity of construction project planning and increases the requirement to truly integrate the elements of a plan. Each change in one of the three aspects will have effects on the other two.

To help students to learn how to generate and change integrated project plans, educators usually base their project management courses on two underlying technical approaches: The cognitive scheme approach and the behavioral approach (Weber 2003). Educators who apply the cognitive approach teach standardized project management methods in a formal way. Educators try to identify the most important methods and assume that students mainly need to internalize the theoretical working of these methods to generate professional project plans. The cognitive learning approaches consider the psychological learning behavior of students, but they hardly help students to learn how and when to apply the learned project management methods in real-world situations. At best, educators help students to learn about possible applications of those methods using relatively basic and abstract assignments. On the other hand, educators who apply the behavioral approach base the students' learning on the assumption that it is possible to learn integrated project management practice by imitating the successful behavior of others. To this end, educators gather experiences, critical incidents, and specific occurrences from practice. Educators assume that telling students these stories helps them to learn how to apply project management methods in real-world contexts. In terms of successful learning, these approaches often fail because they neglect the complexity of the multiple intertwined context specific factors that even for the most experienced project managers require some time to understand. Stories cannot provide the thick context needed to understand how project managers in the past successfully applied the method, but they do not provide the intrinsic technical details and solutions project managers applied in a systematic manner.

To be successful, educators need to integrate both of the traditional learning methods. Such integration requires complex teaching–learning assignments that enable the application of formal project management theories through role-play in simulated environments of real-world project settings (Weber 2002). Only with such assignments, students can internalize integrated project management concepts so that they do not merely learn the concepts, but also develop strategies that allow them to understand when and how to apply these methods in practical contexts. Researchers argued in the past that the advancement of BIM-based project management tools has the potential to overcome practical problems that previously existed with providing realistic project cases within the scope of civil engineering curricula (Peterson et al. 2011). The recent improvements in BIM tools allow educators to provide their students with off-the-shelf software tools that offer them structured support with integrating scope, time, and cost of a project plan in a way that was not easily possible earlier. The application of BIM-based tools reduces the time that students need to spend on some of the labor-intensive scope, cost, or time related modeling tasks and the time that students need to invest in collecting and keying data. Additionally, BIM-based tools theoretically allow the integrated application of several project management tools for one project. For example, BIM-based tools allow the integration of traditional CPM Gantt chart visualization methods of

schedules with 4D visualizations and line-of-balance visualizations (Jongeling & Olofsson 2007). All these advantages together allow educators to design better project-based teaching assignments that allow students to learn how to optimize project plans and to integrate changes.

However, the introduction of BIM based tools in project base project management courses also might hinder students to understand the intrinsic relations between different parts of an integrated project plan. The existing BIM applications tend to automate and black-box important integrative functionality. Not being confronted with these functionality students will not learn the concepts behind them. In the end, students might not be able to completely grasp all elements of scope, cost, and time integration. An alternative to using existing commercial BIM solutions to overcome this problem, is to use available open database and programming means. These allow students to program their own integration functionality, use this programmed functionality on a realistic project to establish a generated project plan, optimize this project plan according to scope, cost, time trade-offs, and integrate changes. The next section, describes a project based class that followed the above strategy. The illustration shows the feasibility of this teaching strategy and provides evidence that students are better able to also understand the intrinsic details of integrated and model based project management activities.

3. ILLUSTRATIVE EXAMPLE: INTEGRATED GLOBAL PROJECT MANAGEMENT CLASS 2013

3.1 Class Setting and process

We illustrate the above claims about the potential of using an open BIM server environment and custom tailored BIM queries during project management classes by describing the implementation of the idea within the Master curriculum of a Dutch university. The Master course that was used to implement the idea is called ''Integrated Global Project Management'' and was followed by 30 students. The class was taught within ten weeks, it stated February 2013 and ended in the middle of April.

Table 1: Outline of the class work

Week	Topic	Project Work
1	Introduction to information modeling and BIM/IFC as an example of an information model to represent buildings	Baseline model in Revit
2	Querying Building Information with an introduction to JAVA programming	Baseline JAVA Queries
3	Quantity based cost estimating	Baseline cost estimate
4	Construction scheduling	Baseline schedule
5	Optimization I: Construction process analysis, construction cycles, cycle calculation	Optimized plan I
6	Optimization II: Sequencing under consideration of technical and logistical constraints, 4D visualization	Optimized plan II
7	Optimization III: Sequencing under consideration of resource and financial constraints, Line of balance, resource leveling, and cash flow	Optimized plan III
8-10	Change management	Plan with incorporated changes

The syllabus of the class is summarized in Table **1** and shows the overall organization of the class around weekly theoretical lectures with related hands-on-work. This hands-on-work was organized around a real world project of preparing a bid for the construction work of a new club house for a local football club. For this project, the students were responsible for developing a baseline model integrating the scope, cost, and time aspects within the first four weeks of the class. In the following four weeks, the students then went through a number of consecutive steps of optimizing their baseline model using selected project management techniques. In the final

weeks of the class, student had to work on the final exam that was comprised of integrating a number of client and non-client induced changes in the optimized project plan and clearly demonstrating the impacts of these changes.
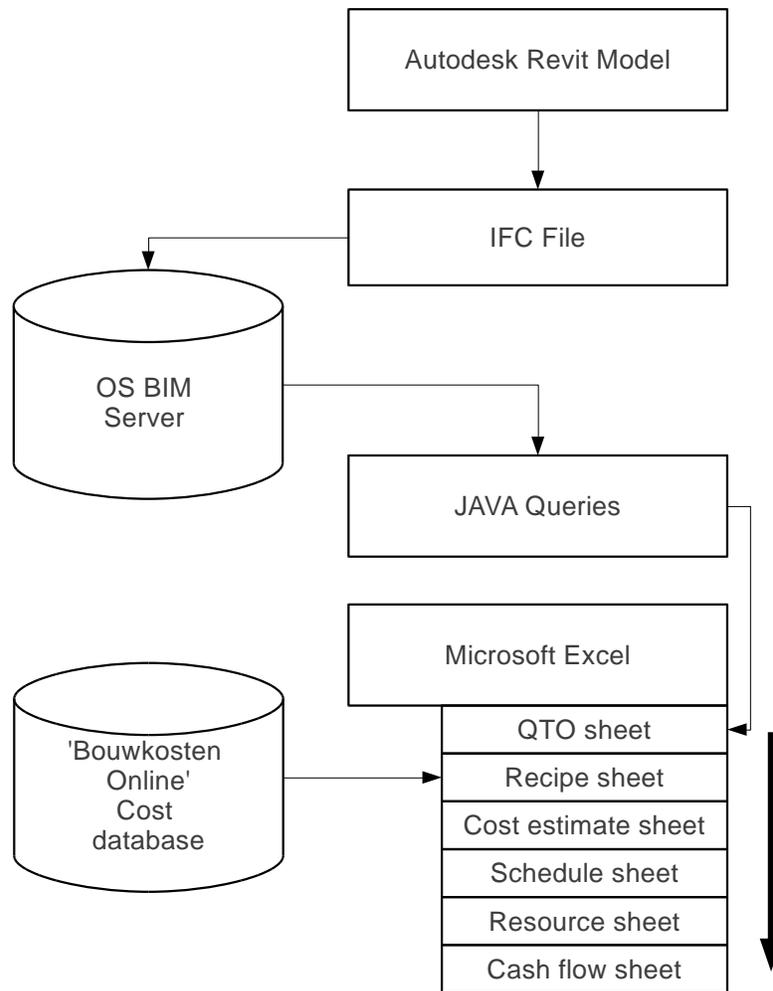

Figure 1: Software architecture implemented by students in the class

Throughout this project work, the students were supported by the software architecture depicted in Figure **1** that they had to establish and set-up themselves. All three-dimensional modeling work was conducted in the Autodesk Revit software and versions of the models were then exported in IFC file format and uploaded on a web based BIM server that was provided for this class.

Table 2: Summary of all queries students developed for the class.

IFC Query Object	Query Property 1	Query Property 2	Aggregation Property	Number of students who used the query
IfcColumn	Phase Created	Reference	Number	8
IfcColumn	Phase Created	Description	Number	7
IfcCurtainWall	Phase Created		Length	3

IfcCurtainWall	Phase Created	Description	Area	6
IfcCurtainWall	Phase Created		Area	8
IfcCurtainWall	Phase Created		Length	4
IfcCurtainWall	Phase Created	Reference	Length	2
IfcCurtainWall	Phase Created	Reference	Area	5
IfcDoor			Number	1
IfcDoor	Phase Created		Number	7
IfcDoor	Phase Created	Reference	Number	11
IfcDoor	Phase Created	Description	Number	4
IfcFooting	Phase Created	Reference	Number	3
IfcPlate	Phase Created	Description	Area	4
IfcRailing	Phase Created		Length	3
IfcRailing	Phase Created	Reference	Number	1
IfcRailing	Phase Created	Reference	Length	1
IfcRoof	Phase Created	Description	Area	4
IfcRoof	Phase Created		Area	4
IfcRoof			Volume / Thickness	1
IfcRoof	Phase Created	Reference	Area	7
IfcSlab			Volume / Thickness	1
IfcSlab	Phase Created		Area	5
IfcSlab	Phase Created	Description	Area	4
IfcSlab	Phase Created		Area	4
IfcSlab	Phase Created	Reference	Volume	1
IfcSlab	Phase Created	Reference	Area	4
IfcStair			Number	1
IfcStair	Phase Created	Reference	Number	8
IfcStair	Phase Created	Description	Number	4
IfcStair	Phase Created		Number	1
IfcWall	Phase Created	Reference	Length	5
IfcWall	Phase Created	Description	Area	3
IfcWall	Phase Created	Reference	Area	7
IfcWall	Phase Created		Area	1
IfcWall	Phase Created	Reference	Area	3
IfcWallStandardCase			Area	1
IfcWallStandardCase	Phase Created	Reference	Length	2
IfcWallStandardCase	Phase Created		Length	8
IfcWallStandardCase	Phase Created	Description	Area	3
IfcWallStandardCase	Phase Created	Description	Volume	1
IfcWallStandardCase	Phase Created	Reference	Area	7
IfcWallStandardCase	Phase Created		Area	1

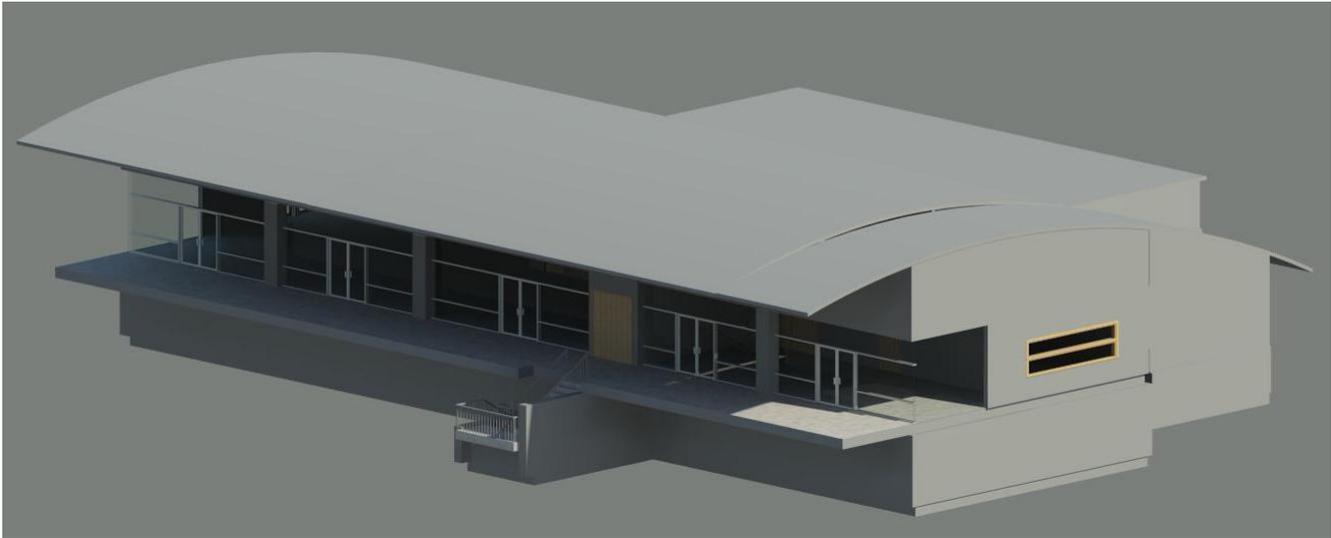| IfcWindow	Phase Created	Reference	Number	6
IfcWindow	Phase Created	Description	Number	3
IfcWindow	Phase Created		Number	1

3.2 Baseline model

Figure 2: Expression of one of the student's Autodesk Revit models

During the development of the baseline model students started with modeling the project in Autodesk Revit. An impression of one of the models is represented in Figure **2**. As a next step, students exported the models to an EXPRESS file in IFC format. On average, these IFC models contained around 300 distinct building objects, such as doors (IfcDoor), stairs (IfcStair), plates (IfcPlate), columns (IfcMember), curtain walls (IfcCurtainWall), and roofs (IfcRoof). Most of the models were divided in six building levels (IfcBuildingStorey): Basement, intermediate level one, level one, intermediate level two, level two, and roof. The ifc files in EXPRESS format were then imported to an Open Source BIM Server (http://www.bimserver.org). Using a SOAP interface and the JAVA programming language students then queried the BIM to extract quantities to a spreadsheet to be used for scheduling and cost estimating. These queries had to extract specific building objects from the BIM server and organize these objects according to a number of properties of these objects. Table **2** provides a complete list of all queries students developed during the class. For example the query in the first row of the table describes a query for all objects of the type IfcColumn of a specific model that groups these columns according to the phase the column was planned to be constructed and a reference that pointed to the type of the column object. For each of these groups this respective query then counted the number of columns per phase and reference. This final outcome was written to a spreadsheet. Using a number of similar queries all students then programmed a complete model based quantity take-off. In a next step, costs and durations of standard construction activities were extracted from a Dutch cost database and linked with these extracted quantities. The in this way generated construction estimate and schedules served then as input for separate spreadsheet to allow for the meaningful evaluation of resource requirements and cash flow.

3.3 Optimized model

After establishing the initial baseline model during the first four weeks of the class, the tasks of the students was then to optimize the model following a number of steps. During the first of these optimization steps students had to consider the detailed construction operations of their baseline schedule. This task involved the selection of a number of costly and repetitive tasks and then plan the construction operation for this task in great detail using construction operations management techniques (Halpin, 1992). An example for such an operation that some

students modeled in great detail was the place reinforcement construction operation, exemplary depicted in Figure 3. Based on the outcomes of these detailed operation analyses the students were then able to adjust their initial cost recipes and duration estimates in their baseline model. A second step in the optimization was then the improvement of the overall scheduled sequence of tasks. To this end, students developed a 4D model (Hartmann et al. 2008) of their initial construction sequence using the Autodesk software Navisworks. 4D models are helpful for visually examining global construction sequences and finding spatial conflicts within sequences. It is not surprising that students were able to adjust their overall scheduled project duration within this step. After optimizing the sequence students than established a line of balance schedule to support them in their resource leveling efforts. Line of balance tools work well to adjust the allocation of resources to repetitive activities (Jongeling & Oloffson 2007). Figure 3 also shows an example of one of the student's line of balance schedules. Again students integrated optimizing changes into their model based on problems they realized with resource leveling using the line of balance technique. Finally, students had to optimize their model according to the final profit expected for the contractor using a cash flow calculation (also see Figure 3 for an example). Throughout these optimization steps, students could easily integrate changes in their baseline model because of the connected nature of the models. It was possible to experiment with alternatives seamlessly and truly optimize the model through each of the optimization steps. The outcomes of these optimizations compared with the baseline model is summarized in Table 3 using the mean results of the students.

Table 3: Means of costs estimated by the students in the baseline model and optimized model compared with the contractors estimate.

	Cost	Δ real estimate
Baseline	€ 498391.20	€ -291030.80
Optimized	€ 596202.00	€ -19322.00

3.4 Change integration and management

During the final part of the class, the students had to work on their final assignment. This assignment asked them to incorporate a number of changes in their existing project plan and to evaluate the changes on a global project plan level. Overall, students had to incorporate three different potential change scenarios:

- A change in the initial design of the reference building that required them to extend the design with an additional space and estimate the additional costs and construction time this change would entail.
- The client request to crash the schedule to allow for the delivery of the project three weeks earlier that planned in the optimized project plan.
- Possible ramifications because of the default of one of the main material suppliers in relation, to cost, schedule, and cash flow.

One purpose of this final assignment was to test the level of integration of the optimized project plans students had developed earlier. From the final reports of the students it is apparent that the incorporation of these changes, accounting for different alternatives to do so, went seamlessly because of the integrated nature of the project plans. This allows students to focus on finding creative solutions to account for these changes without the need to invest much time of calculating new versions of their plan.
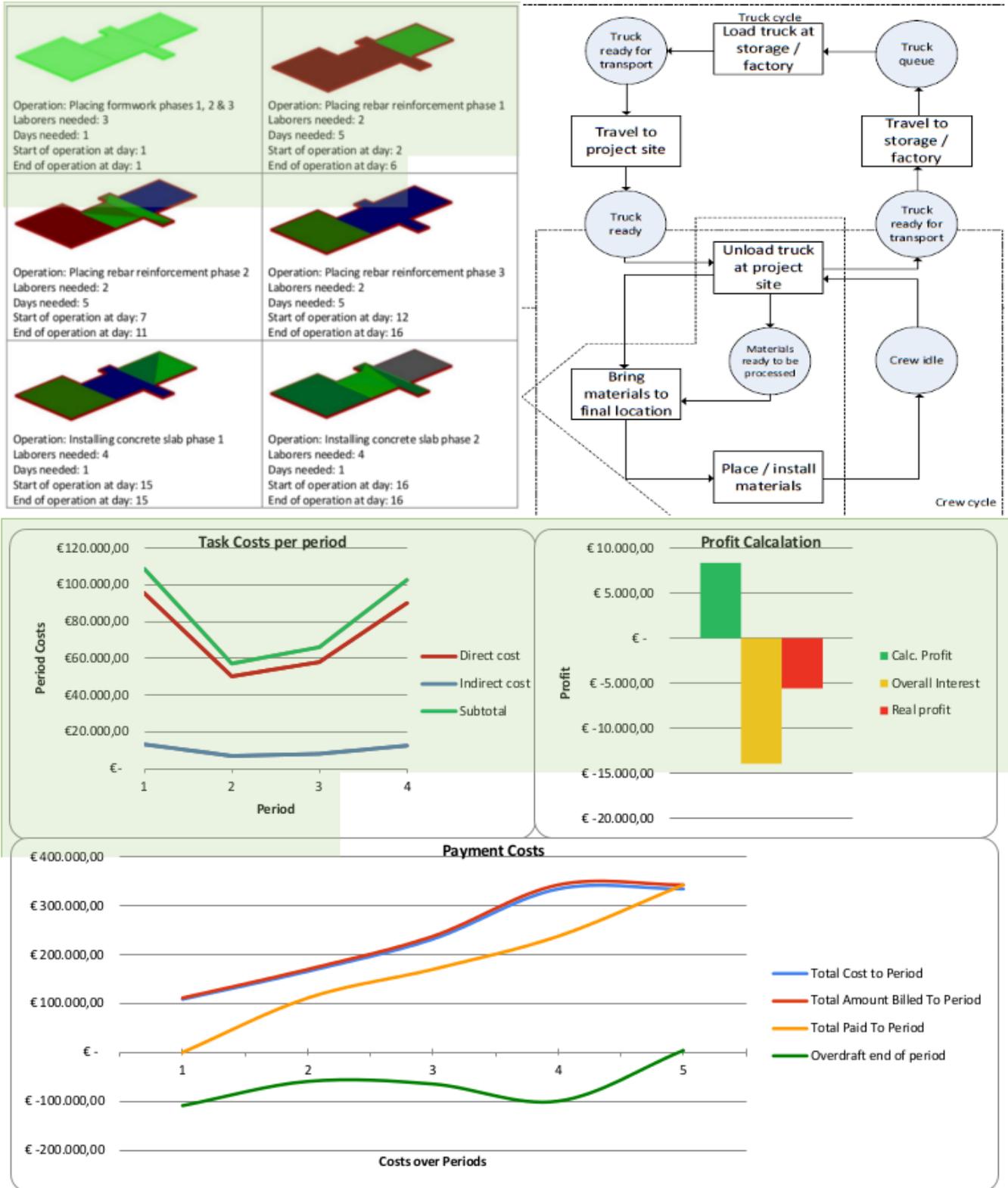
Figure 3: An example of a 4D model, a LOB diagram, and an operations process diagram

4. CONCLUSION AND FUTURE WORK

All in all, the outcomes of the class showed that it is feasible to teach integrated and model-based project management without the use of the existing commercial solutions. All students that followed the class were able to develop their own integrated project plan solution using a combination of low level tools, such as an ifc BIM server, JAVA queries, and spreadsheet software. The outcomes of the final assignment shows that students were able to develop integrated project plans that allowed them to quickly test and understand different interventions at the global, overall cost-time-scope level of a schedule. These results are similar to earlier classes we taught during which used commercial software applications. However, the new class format additionally helped students to understand the underlying principles of integrated model-based project planning that were black-boxed by the commercial software used within the previous classes.

The above claim is underscored, for example, by the struggles of the students with the contents of the model and how to best query the models. It became obvious that many of the problems students had were not related to technical problems with the JAVA code itself, but were related to missing elements in the model or a misunderstanding about the composition of the ifc model and the properties of the model's objects. The open ifc format with its possibilities to browse ifc objects and query their property sets helped students to overcome many of these struggles. Through that process, students gained an in depth understanding about the structured of the ifcs. It can be assumed that this in depth understanding of information models to describe buildings would not have been gained if the students had used commercial software products that tend to black-box the underlying information model functionality.

Of course, there are some risks involved in teaching classes similar to the one described here. Maybe the biggest risk is that construction project management students usually do not have a background in software programming. Hence, the step towards programming their own code in JAVA is daunting at the outset. Educators, hence, need to provide well designed and structured introductory courses to JAVA programming and information modeling[1]. Additionally, clear cut templates and descriptions of how to query building information from a server need to be provided. At the same time, it is important that teachers safeguard the focus on project planning throughout the class. The experiences from the above described class shows that some students started focusing solely on software programming in an effort to improve their developed software solutions. These students at times forgot the general purpose of their development work: The support of project planning decisions and the improvement of project plans. Sound incentives need to be installed to set the main focus of students on the task of developing well thought out project plans.

Nevertheless, the expected merits of teaching a project planning class in the above described manner justify taking the above described risks. Having a deeper understanding about the underlying information modeling concepts behind integrated project planning class, it can be very well assumed that students will be able to more readily be able to grasp the functionality of existing commercial project planning solutions. Moreover, by understanding the underlying concepts of these solutions, students will be able to trouble-shoot problems within the software easier. Many issues around the use of integrated project planning solutions in practice after all are caused by inadequate information models of buildings that do not allow for the meaningful extraction of quantities. Students will be able to better define information modeling requirements in general, and to evaluate specific model instances on a particular project according to their suitability to support integrated project planning tasks. Finally, and probably most importantly, the in depth understanding that students gained in this class equips them to meaningfully discuss with software companies about the needs and requirements of building information modeling software, or to develop own company specific solutions. Therefore, students following this class will be better able to strategically move BIM implementations forward in practice and become leaders within their companies.

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[1] The material used for this class is available as open source project at https://github.com/timoutwente/IGPMBIM. We hope that this project will be helpful for other educators to design similar classes.

In conclusion, if nothing more, this paper shows that it is feasible to teach integrated and model based construction planning without the reliance of commercial software tools that would black-box many of the underlying construction planning concepts. In the end, classes designed similar to the one introduced in this paper can help to prepare students for a construction management practice that embraces more and more the use of model-based techniques and that is more and more confronted with the complex task of more tightly integrating the cost, time, and scope aspects in their planning activities.

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