Introducing Interdisciplinary Collaboration into Design Curriculum

Identifying the Appropriate Technological Infrastructure

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Abstract: *There is an increasing adoption of BIM technology in the AEC industry. Organizations are forced to restructure their practices. The role of the architect within the new multi-disciplinary design team will depend on the architects' skills in communicating with other team members. Architecture schools need to prepare students for this change. Collaborative aspect of design should be incorporated into the curriculum. This paper reports on the collaboration initiative between the architecture and civil engineering departments at Balıkesir University. The initiative is investigating the extent to which courses can be coordinated across departments. Students from three different courses have been asked to provide analysis and feedback for the same project concurrently. The results confirm that BIM technology can effectively support collaboration even among undergraduate students who are relatively inexperienced with interdisciplinary data exchange.*

Keywords: *BIM; collaboration; curriculum.*

Introduction

Building Information Modeling (BIM) technology promises to alleviate problems associated with the excessive fragmentation of the building industry. As data exchange possibilities that come with BIM encourage the participation of various disciplines earlier in the design process, issues related to the collaborative aspect of design are coming into the spotlight. The design process is more and more a multi-disciplinary team effort.

Integrated design processes of multi-disciplinary design teams require reasoning based on explicit knowledge in order to exchange ideas, evaluate tradeoffs and avoid conflicts. However, the crux of the work of architects lies in tacit knowledge. Traditionally, this misalignment has caused engineers to avoid interactions with architects while architects ask for performance analysis only for verification purposes after the completion of design. If architects are to assume a leading role in the new collaborative approach to design, they have to discover ways with which they can communicate their design decisions in terms of explicit knowledge in the overlapping areas among various domains of specialization.

BIM technology offers designers possibilities towards exploring the impact of design decisions on performance indicators in various domains in order to avoid apparent pitfalls during early design. BIM technology is labeled as a disruptive technology by Eastman et al. who in their recent book discuss in detail how the AEC practices are being transformed (Eastman et al., 2008). Yet, it is still not clear how AEC organizations should structure design teams and how the integrated design process should move forward. Issues such as concurrent design, validity of analysis results, process management are still not addressed. Most research efforts are still dealing with the technical infrastructure and in the meanwhile architecture and engineering education is falling behind in preparing students for multi-disciplinary teamwork that awaits them in the BIM era. The collaborative aspect of design should be included in architecture curriculum.

The collaboration initiative

In order to prepare architects and engineers for this transformation, institutions should investigate how students can experience collaborative decision making during their education. This study reports findings from the second phase of a collaboration initiative that was started in February 2008, between the Department of Architecture and the Department of Civil Engineering at Balıkesir University.

The main objective of the initiative is to provide a platform for students to experience the multi-disciplinary nature of the building design-delivery process and better understand their responsibilities towards other members of the design team by coordinating courses across departments and planning common projects where students from different disciplines collaborate.

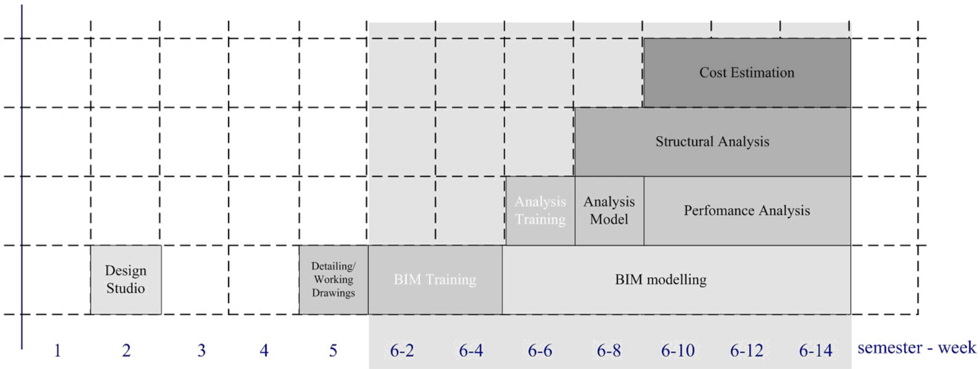
Usually courses are conducted in isolation. They focus on performing an individual design task with set assumptions about requirements of other disciplines. This is in parallel with common industry practice that considers the design delivery process largely a sequential set of activities. The need for collaboration is acknowledged and handled in one of two ways according to Kalay (2006): "Hierarchical decision making and temporally partitioned responsibilities." Kalay (2006) points out that in both cases the overall result is less than optimal and that the design process should be considered an interleaved process rather than a sequential one. The initiative is planned as a step forward towards this type of interleaving. Data portability inherent to BIM opens up the possibility to link courses without requiring additional coursework for introducing data exchange methods and tools. Linking courses across departments will allow design alternatives to be explored collaboratively. Also linking courses chronologically will allow students to assess the impact of early design decisions as they are carried forward through various stages.

The collaboration in its second year coordinated three courses: A group of architecture students, in the third year Building Physics course, explored alternatives to improve the thermal performance of houses they designed and detailed in previous semesters. Simultaneously, these designs were subjected to structural analysis by civil engineering students as part of the fourth year Graduation Project course. As design alternatives were compared cost implications were also taken into account. Cost estimation was carried out by fourth year architecture students as part of the Project Management course. The schedule of tasks is shown on the timeline in Figure 1.

Background and previous results

The first phase of the study took place during the spring 2008 semester. In that first attempt an ad-hoc approach for dealing with technological issues was adopted. The premise then was that BIM/IFC technology was mature enough to allow efficient data exchange among the various domain applications students would be utilizing. Many successful applications of IFC can be found in literature. Chen et al. have developed an IFC based web server for

Figure 1
The planned schedule



collaborative building design between architects and structural engineers where design data from IFC compatible CAD systems are automatically transformed into a structural model (Chen et al., 2005). Fisher and Kam documented in detail the utilization of IFC in an actual construction project and concluded that the IFC based data exchange in comparison with traditional practice improves the quality of interdisciplinary collaboration (Fisher and Kam, 2002).

However, it soon became clear that in an undergraduate classroom setting the IFC based data exchange features of available BIM based software tools were not yet working as advertised in most cases. In-house solutions needed to be devised for data exchange. Discovering work around solutions consumed too much time. These workaround solutions were also not likely to scale up especially for large projects. The decision to stick with a simple file based operational environment rather than elaborate model servers and a simple design task allowed students to at least complete their tasks. From the technical standpoint, the ad-hoc approach failed to provide a satisfactory computational environment. Students were not able to explore multiple alternatives. However, overall, the students had a positive response towards their experience. Thermal performance analysis that was carried out by the architects, allowed these designers to discover how domain expertise can improve designs based on objective measures. As their confidence in their work increased, they were more eager to work with the civil engineering students who similarly relied on analysis results when generating alternatives. This positive attitude provided the motivation for a second attempt.

Second phase

After the first phase failed to define an appropriate technical infrastructure for effective collaboration, the second phase had to continue the search for the right tools and methods. The second phase of the study was carried out during the spring 2009 semester. The tasks and planned schedule was preserved as shown in Figure 1. In this second attempt, students were given tools offered as part of a single BIM suite that offer custom links rather than rely on IFC based exchanges. This time the premise was that proprietary solutions should be more effective. Autodesk was the chosen BIM vendor for the experiment. Revit Architecture was used for modeling by architecture students. Revit Structure was utilized by civil engineering students to manage links with Probina Orion structural analysis package. Autodesk Ecotect software was used for thermal analysis. Quantity Takeoffs from Revit Architecture were used for cost estimation. Compared to just relying on the IFC standard, Autodesk custom solutions provided a smoother data transfer as expected.

The virtual model

Architecture students design two-storey houses in their third semester studio. Later in the fifth semester Working Drawings course they design details and prepare working drawings for these houses. The detailed nature of the designs makes these houses good cases for our collaboration experiment during which, even the architecture students will focus on performance analysis and evaluation.

The working drawings that the current students had produced were all conventional 2D drawings. Therefore, first, a virtual model for the houses had to be built. During the first four weeks of lab sessions basic training for Revit Architecture was given to architecture students. Afterwards the students were expected to complete the virtual models for their houses in two weeks and this task was completed on schedule. An example of a virtual model is shown in Figure 2.

Data exchange between designers and engineers was trivial. Revit Architecture and Revit Structure use the same file format and thus there was no need for data translation of any kind. However, the initial models sent to Civil Engineering students unveiled a major problem unrelated to data exchange. The architecture students were building their models for mostly visualization in mind but for the engineers, beyond geometry, the semantics of the elements used in the model was vital. Revit provides both architectural and structural components for basic building elements such as slabs and columns. Architects were utilizing whatever was convenient to them and a combination of these elements existed in the virtual models. As a result the models looked fine but were inconsistent for analysis. The models were revised using only Revit's structural components. After this initial revision, other problems were discovered and had to be fixed. Three important ones were:

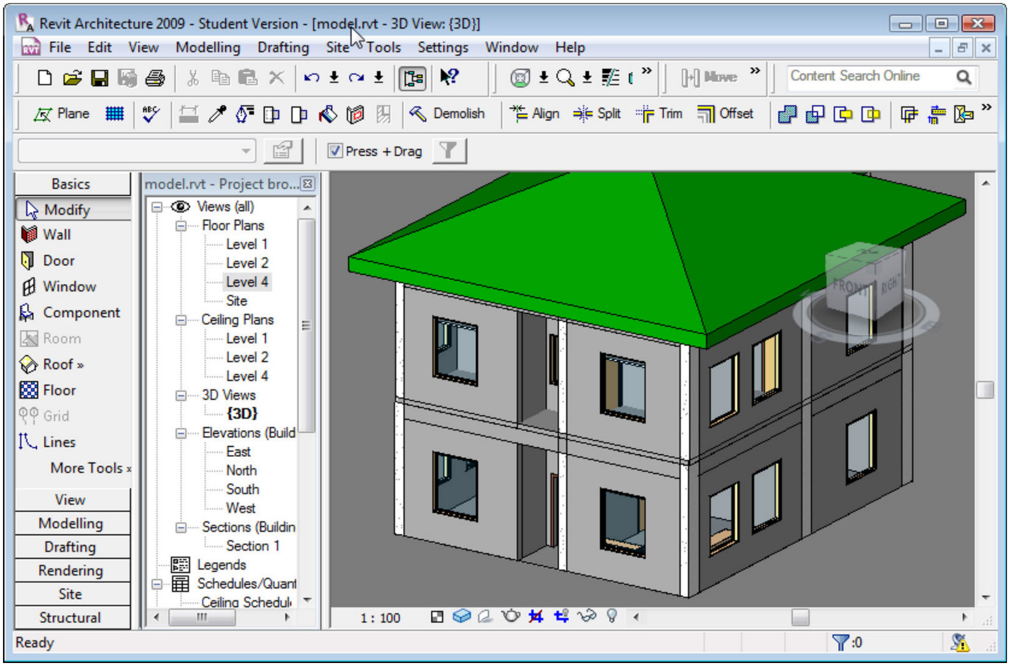


Figure 2
A virtual model in Revit Architecture

1. Architectural and structural components that intersect were not properly handled by Revit Structure. The overlapping areas present no problems for architects, but prevent an analytical model to be built. Every wall's height had to be adjusted so as to avoid intersecting beams and slabs.
2. Building levels define where columns are divided during analysis. Unused levels had to be cleaned up and unnecessary utilization of levels (for example for raised platforms) had to be avoided.
3. Elements that are added to the model with names such as a "Column 25x40" and later resized were not renamed by the designers. Revit Structure processed these elements with a tag that refers to the names that do not reflect their sizes causing confusion for the engineers.

As the virtual models were undergoing revisions, group sessions were conducted between architects and engineers in order to agree on the general design of the structural system and issues such as column placements. The models were completed and passed on to the engineers and project managers with a three week delay.

Energy analysis

Students were introduced to the fundamentals of Energy Analysis in class as the CAAD model was prepared in the lab sessions during the first four weeks of the semester. Afterwards, Autodesk Ecotect Analysis software was to be introduced in the lab but this was delayed for three weeks. Ecotect is an integrated multi-domain analysis environment that includes comprehensive visual modeling capabilities (Roberts and Marsh, 2001). With a graphical user interface and a steady-state thermal simulation engine, Ecotect is a good tool for demonstrating the relationship between design variables and basic thermal performance indicators. After covering Ecotect in the lab for two weeks, students were asked to conduct thermal analysis of their designs. Ecotect was utilized the previous year but had failed to exchange any form of data with the CAAD tool. The analysis models were built from scratch. This year, the latest version of Autodesk Ecotect Analysis had improved its support for gbXML import. Revit models were successfully imported into Ecotect but the gbXML models Revit produced were too detailed for the simple analysis students were to carry out. Too many unnecessary surfaces were created and cleaning up the models was an arduous task. While this task was time consuming, it clearly demonstrated the differences between architectural modeling and modeling for thermal analysis to the students. Due to the delays in completing the virtual model and the analysis model, students were not able to explore multiple alternatives in the lab as was initially intended. An example analysis model as imported from gbXML is shown in Figure 3.

Structural analysis

The civil engineering students in their fourth year Graduation Project course were introduced first to Revit Structure and then to the use of Probina Orion in the first half of the semester. Probina Orion is a structural analysis software with a 2D/3D modeling environment that integrates design, analysis and drafting capabilities for reinforced concrete building structures. Probina Orion provides custom links with Revit Structure as an add-on. This add-on provided effective import/export capabilities with minor limitations. The following was not carried over during the data transfer: Loads, slabs, foundation elements, reinforcements, openings in shear walls, non-rectilinear walls/beams, prefabricated columns/beams, materials, and polygonal columns.

Engineers discovered the following points that had to be addressed while preparing an analytical model in Revit Structure:

1. A complete structural grid was required for analysis.
2. Column/beam connection eccentricities had to be individually resolved.

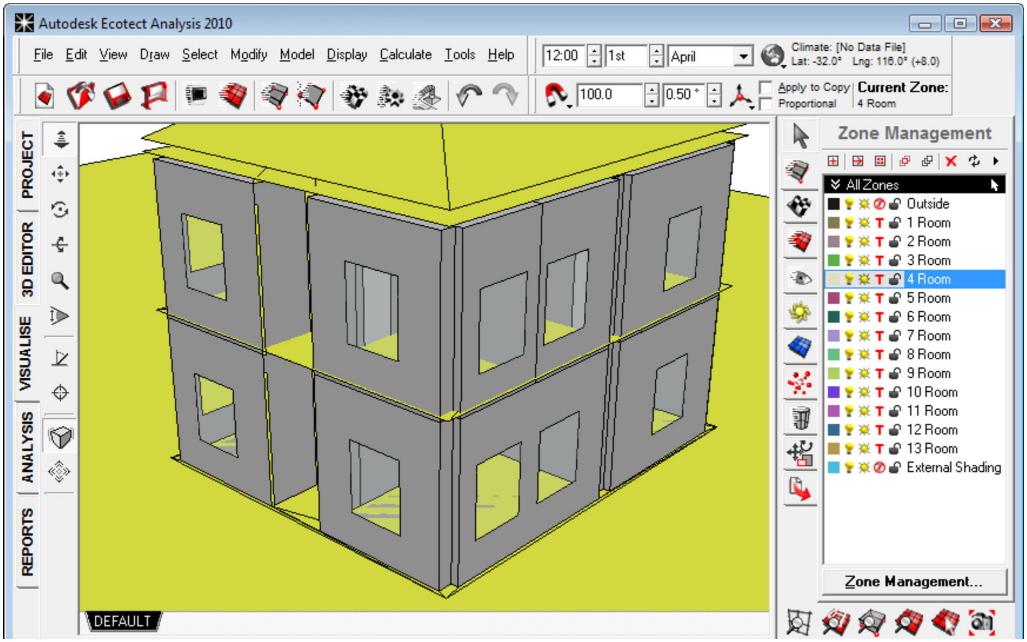


Figure 3
Revit's gbXML analysis model in Ecotect

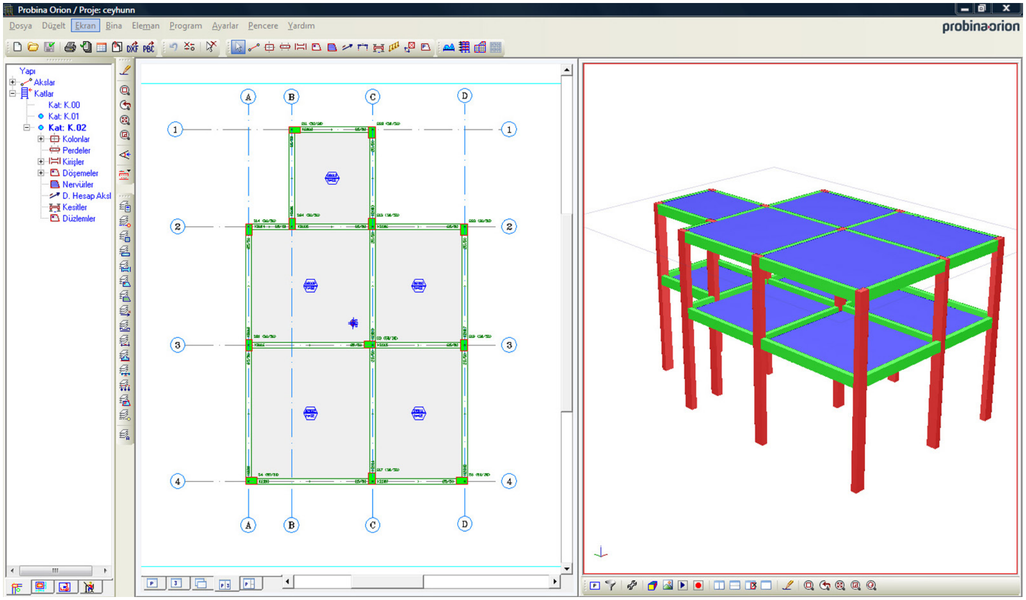
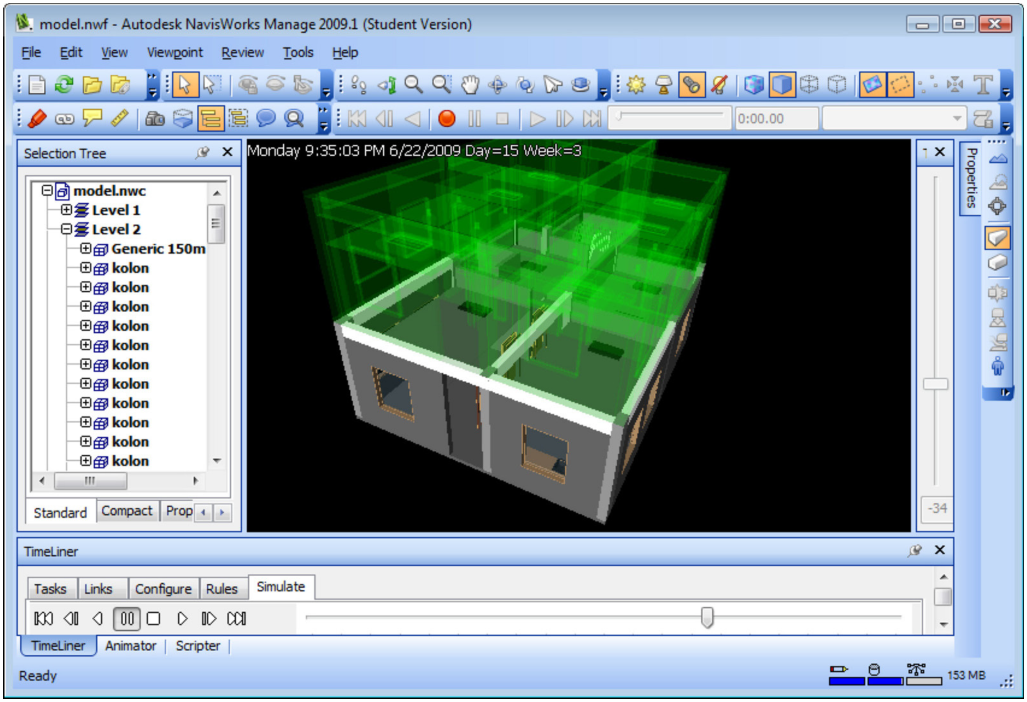


Figure 4
Structural model in Probina Orion

Figure 5
4D Simulation in NavisWorks



3. Beam heights had to include slab heights and the z-directions had to be checked and corrected.
4. Due to Probina Orion's automatic handling of slabs, beams had to be modeled separately from their slabs.

Due to delays, civil engineering students only had two weeks for analysis. Updating of the architectural models during in class sessions could not be completed but results have been communicated through the course website. An example structural model is shown in Figure 4.

Project management

Architecture students in the fourth year Project Management course provided cost estimation and prepared project scheduling for the construction of the houses. All BIM tools are capable of providing bills of quantities (BQ) with relative ease. However, no tools are available for cost estimation in the Turkish context appropriate for the early stages of design. Students provided cost estimates using an Excel spreadsheet based on CPR Software's, General Cost Estimator tool. BQs from Revit were plugged into this custom spreadsheet. Project scheduling was carried out using Microsoft Project based on a 50 activity schedule. Additionally, a 4D simulation of the construction sequence was generated in Autodesk NavisWorks (Figure 5). Although delays in model preparation prevented multiple design alternatives to be evaluated, students were able to carry out the tasks on schedule.

Conclusions

Choosing software from a single CAD vendor's suite of BIM tools has created an acceptable platform for the collaboration initiative at Balikesir University. Students fell behind schedule and only achieved limited success. However, the delays were mostly due to problems associated with modeling habits rooted in traditional CAAD tool usage and not due to lack of functionality in software. The 3D architectural model is no longer only a visualization tool. Architects need a better understanding of the requirements of various disciplines that will rely on the model. They also need to follow a more rigorous process in building the model. BIM technology is challenging the established modes of use for CAAD tools. Constraints from various disciplines need to be integrated into future design tools. This may be in the form of advanced parametric modeling systems such as the one outlined by Lee, Sacks and Eastman (2006). Until then, one way to avoid excessive revisions of models is by preparing detailed modeling guidelines for designers.

Overall, the students have responded positively towards the collaboration. They were eager to interact with actual partners rather than work with set assumptions about other disciplines. The evaluation of thermal performance that was carried out by the architects themselves, allowed these designers to discover how objective measures are utilized by domain experts. As a result they were more open to working with civil engineering students who similarly rely on analysis results when generating alternatives. This increased utilization of explicit knowledge is likely to have a positive impact on the future role of the architect within the multi-disciplinary design team.

Next year, instruction for a BIM based CAAD system will be provided as part of the Working Drawings course and students will gain at least four weeks to generate and evaluate alternatives for their designs. Also, until now the focus of the study has been on resolving technical issues, however, in the next phase, students' before and after expectations, attitudes and experiences should be documented and analyzed. Currently a post-mortem analysis is being prepared with the aim of documenting students' experiences and lessons learned.

In the future, possibilities for including other departments and other institutions will be explored. Furthermore, how design studios can benefit from taking part in such collaborations requires investigation.

Finally, it should be stressed that while working only with software that are integrated with a specific BIM suite provides an adequate technological infrastructure for collaboration, solutions based on open standards such as the IFC should be preferred in the future. BIM will not be able to alleviate the problems associated with the excessive fragmentation in the building industry if the current trend of competing proprietary integrations is continued.

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