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RESUMEN

En el entorno competitivo de la actualidad, la Arquitectura, Ingeniería, e Industria de la construcción (A / E / C por sus siglas en inglés: Architecture, Engineering, and Construction), los servicios profesionales que compiten en el mercado para satisfacer las necesidades de los propietarios en cuanto a calidad, eficiencia, costos, y control horario. Para satisfacer estas necesidades, la industria está experimentando cambios fundamentales basados en la integración de las funciones realizadas por las empresas. Para atender las necesidades educativas derivadas de una mayor integración en la industria, en 1993 el Departamento de Ingeniería Civil y Ambiental en el Instituto Politécnico de Worcester (WPI) implementó el Programa Maestro de obras. Un curso de postgrado a nivel de la CE 535 Integración de Diseño y Construcción se desarrolló y se ofreció por primera vez durante el semestre de otoño de 1995 como parte del Programa del Master Builder. Con los años, los dos instructores de clase se han adaptado a los principios de la ingeniería de valor como un modelo pedagógico para entregar el material del curso y establecer un marco formal para apoyar el análisis racional y la toma de decisiones para la integración de diseño, construcción y planificación financiera. Ahora que los estudiantes IPM son cada vez más expuestos al uso de software 3D-OOP programación orientada a objetos y al concepto Building Information Modeling (BIM); el CE 535 se está revisando para exigir a los estudiantes a la utilización de las herramientas BIM y conceptos como parte integral de su desarrollo del proyecto. Para lograr esto, una parte de los laboratorios se dedicarán ahora a facilitar el aprendizaje de los estudiantes de esos elementos BIM que son necesarios para el desarrollo de su proyecto a largo plazo. Este artículo presenta la elaboración de un tutorial que es desarrollado principalmente por el tercer autor durante el verano del 2010. Este tutorial tiene por objeto guiar a los estudiantes en el uso de Autodesk Revit en su proyecto a largo plazo, ya que poco a poco aplicara su experiencia, respondiendo a una solicitud de propuesta para el diseño y construcción de un estacionamiento situado en Lexington Street, Worcester, MA.

INTRODUCTION

In the competitive environment of today's architectural, engineering, and construction *(A/E/C)* industry, professional services are competing in the market to meet owners' requirements for quality, efficiency, cost, and schedule control. To satisfy these needs, the industry is experiencing fundamental changes based on the integration of functions performed by the firms. These changes can be observed in the increased use of partnering arrangements, use of design-build and integrated project delivery contracting approaches, as well as of project front-end loading including constructability and value engineering analyses, initially in the private sector, and now in the public sector as well. They can also be observed in the emphasis on the development of efficient project teams, the use of alternative dispute resolution methods, and the embracement of the Total Quality Management and Lean Process concepts that promote a client-server relationship.

To address educational needs arising from increased integration in the industry, in 1993 the Department of Civil and Environmental Engineering at Worcester Polytechnic Institute (WPI) implemented the Master Builder Program, which leads to a Master of Engineering degree (Albano *et al.* 1999). A graduate-level course CE 535 Integration of Design and Construction was developed and offered for the first time during the fall semester of 1995 as part of the Master Builder Program (Albano & Salazar, 1998). The goal of the course has been to provide a project-based, practice-oriented opportunity for teams of students to deal with the problems of functional integration. It has been taught by the first two authors of this paper whose backgrounds are in the areas of structural engineering and construction management. They both equally participate in the delivery of this course. Since 1997, CE535, a three-credit-hour, one-semester course has been offered every other year.

The backgrounds of the students who are expected to enroll in CE 535 are representative of the various disciplines involved in the project development process, such as architecture, structural engineering, mechanical engineering, electrical engineering, and construction project management. However, past experience shows that given the nature of the graduate programs offered by the civil engineering department a significant majority of these students have a background in structural engineering or construction project management.

MEANS & METHODS

Over the years, the two class instructors have adapted the principles of Value Engineering as a pedagogical model to deliver the course material and to establish a formal framework to support the rational analysis and decision-making for the integration of design, construction and financial planning. They have also incorporated lessons learned from previous offerings

The flow of activities within CE 535 is driven by the development of a group term project and involves a mix of class discussion, laboratory, and lecture activities. The instructors rely on industrial participation to introduce real-world situations into the term-project and to directly convey these to the students. The students also review the current research and best practices related to the design-build delivery method. Use of Information Technology (IT) is discussed and briefly reviewed in class, and the students are strongly encouraged to use IT to support the development of their term project. Therefore, students who previously have acquired knowledge in the use of software applications such as AutoCAD®, EXCEL® spreadsheets, PRIMAVERA® and TIMBERLINE® use these packages on their own initiative in preparing their work.

Over the last fifteen years the construction industry has been slowly but surely experiencing a gradual shift in the way that the design-build process of buildings and infrastructure projects are conducted. This is due to the advent of powerful 3D Object-Oriented Parametric (OOP) software and its intrinsic relationship with the concept of Building Information Modeling (BIM). BIM is a collaboration-enabling technology: it allows fundamental information that is needed for the coordination of a project's design, construction and operation to be captured in digital models at the time design objects are created. The advantages that this software offers provide strong premises to overcome the fragmented nature of the industry. As a result the industry is likely to see new emerging processes that replace the traditional separation of design, construction and facilities management.

The WPI Department of Civil and Environmental Engineering has already implemented two courses in its curricula to educate students in the BIM concept and to provide skills in the use of the software. At the undergraduate level one course teaches students the basic use of this software in the context of a collaborative design and construction (Salazar & Conron, 2009); whereas, at the graduate level a second BIM course emphasizes the professional and research implications of this technology. In addition to these formal course offerings, some students also work with BIM as part of their undergraduate projects or graduate theses.

The first two authors have long recognized BIM's inherent integrative nature and have presented the concept of a shared computer-based building model within CE 535. Now that WPI students are increasingly exposed to the use of 3D-OOP software and the BIM concept, CE 535 is being revised to require the students to use BIM tools and concepts as an integral part of their project development. In order to accomplish this, a portion of the labs and homework assignments will now be dedicated to facilitate students' learning of those BIM elements that are necessary for them to develop their term project. Therefore, a tutorial document is primarily being developed by the third author during this year's summer. This tutorial is intended to guide students in using Autodesk REVIT software in their term project as they gradually proceed through their experience in responding to a Request for Proposal (RFP) for design-build services of a parking facility expected to hold 414 cars at the WPI's Gateway property, located on Lexington St, Worcester, MA. In addition, the facility must have 3,875 square feet of commercial space. As part of the scope of work for the students, they design the site and architectural layout, explore preliminary structural designs, perform a constructability analysis including preparation of cost estimates and schedules as well as address the financial and economic aspects of the proposal such as cash-flow and risk analysis.

There are several BIM tools that will be used by the students in the future development of their proposal. Two of these BIM tools (REVIT Architecture and REVIT Structure) will be the primary ones. No prior knowledge of any of the programs used will be assumed; therefore special attention has been given in having the tutorials present a step-by-step approach to the students with detailed explanation on how to complete the step. A comprehensive package of REVIT files has been compiled, capturing the status of each tutorial throughout its progression. This allows the student to enter a tutorial at any point and work as if he/she had completed all prior steps. The tutorials were prepared using the latest software version: the REVIT 2011 suite. The detailed explanations are expected to provide enough insight into the process so that the tutorials are readily adaptable to later releases of REVIT.

RESULS AND ANALYSIS

The tutorial material is organized into six modules according to the major tasks students go through in the development of their term project. These include:

- Developing an Architectural Model
- Developing a Structural Model
- Using BIM for Structural Analysis
- Development of a Complete Model
- Extension of the BIM Model for Construction Management
- Exploration of Probabilistic Estimating and Risk Analysis

Each of these modules is in turn organized into a series of smaller lessons dedicated to help the students accomplish the overall purpose of the module. For example, *placing columns* is a separate task from *placing a floor*, although both of these tasks are part of developing the structural model. There is an instructor's guide for each of the tutorials. The guides provide general direction and objectives for the tutorial, list all supplementary materials included in the module, and define the specific files and information to be distributed to the students. The supplementary materials contain REVIT-related files showing different stages of completion and additional resources, such as narrated videos, internet hyperlinks, spreadsheets and other complementary documentation. The following section illustrates one of the many lessons included in Tutorial 3: Using BIM for Structural Analysis. The lesson guides the student in creating a column schedule within REVIT and exporting the schedule to Microsoft Excel, which may serve as input to structural analysis and design tools.

CREATING AND EXPORTING A COLUMN SCHEDULE TO EXCEL

File Establishment: Open XXXtutorial3_1 in REVIT Structure 2011 (or WPItutorial3_1) and save the project as XXXtutorial3_2, where XXX is your initials.

Introduction: In this lesson you will create a column schedule in REVIT and export it to a text file, which you will then open in Excel.

From the view ribbon, choose "Schedules" > "Schedule/Quantities". In the New Schedule popup, choose "Structural Columns" and click "OK"

In the Schedule Properties popup, select each of the following, clicking Add after selecting each: Analyze As, Base Level, Base Offset, Bottom Release, Family, Family and Type, Length, Top Level, Top Offset, Top Release, Type, and Volume. Click "OK". The schedule will open, and in the Project Browser you will see that Structural Column Schedule now shows up under Schedules/Quantities.

Click ▲ in the top left of REVIT, and choose "Export" > "Reports" > "Schedule". Choose the appropriate place to save the file, and name it XXXtutorial3_2. Click "Save". In the Export Schedule popup, change "Field Delimiter" from "(tab)" to ";". Click "OK".

Open a new Excel file and save it as "XXXtutorial3_2. Now open the text file created in the previous paragraph. Highlight and copy all of the text. Go back to the Excel file, click in cell A1, and paste the copied text. Near the bottom of the screen you should see a symbol that looks like 📋. *Click on the symbol and choose "Use Text Import Wizard…". Click "Next" on the popup. In the next popup, select "Semicolon" and unselect "Space". It should now look like*:
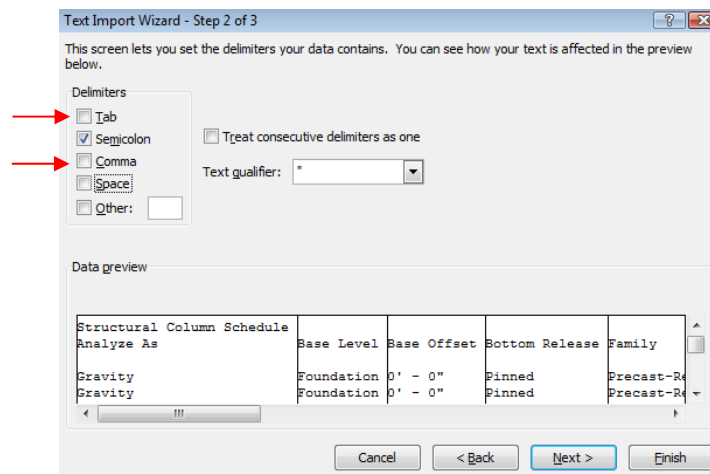
Click "Finish". The data is now sorted into columns similar to the schedule in REVIT.
Wrap-Up: You have now created a column schedule in REVIT, and exported information to Excel. Save the Excel file. In REVIT, return to the Level 1 Floor Plan, close hidden windows, and save the file.

CONCLUSIONS AND FUTURE WORK

The tutorials were completed and tested by the end of summer of 2010. The syllabus for CE 535 is now being adjusted accordingly to harmonize the lecture materials with all homework assignments and term project. CE 535 will not be offered until the fall of 2011. By then, it is likely that a newer version of the REVIT software will be deployed by the software vendor thus creating the need for testing the robustness and compatibility of the material documented in the tutorial and to make necessary adjustments. This test and adjustments will be done during the summer of 2011. However, it will not be until after the completion of the fall-2011 version of CE535 when the instructors will find the real benefits and challenges of incorporating and mandating the use of BIM tools in this course. Regardless of these results, the instructors are fully compelled and dedicated to take this route if CE535 is to stay relevant and to serve the purpose for which it was created.

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