From Fragmented to Integrated Project Design & Delivery: Student's New abilities and Future Direction in Curriculum

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ABSTRACT

This document describes the transformation of the construction industry in the last few years due to the introduction of the BIM (Building Information Modeling) and the cloud. BIM base design and construction changed a fragmented industry into an integrated Project Design and Delivery with many advantages for of all the players involved. This transformation requires professionals with more knowledge and new abilities to respond to those changes. How could faculty respond to this new challenge? How could they include those changes into the already heavy curriculum? This document presents a proposal on how to transform the program without doing many changes in the curriculum and embedding the topics into the classes.

Keywords: BIM, Integrated Project Design and Delivery, Construction Management, Curriculum Changes.

1. INTRODUCTION

Historically the construction industry changes were slow, but in the last few years the trends and changes are happening at an accelerated rate. The new requirements in the market like building information modeling (BIM), sustainable construction and the responsibilities with the environment for disposing the buildings after their life span expire are only the beginning of these changes.

Before and after CAD (Computer Aided Design) came on the market, we were accustomed to a fragmented industry where one professional, for example the designer, finished his or her work and another professional continued it, (for example the structural engineer) adding the next piece of the project that is followed by the mechanical and electrical engineers before the construction starts. When the construction finished, the building wis turned over to the owner who occupy it and a new professional, the administrator, would take care of the building maintenance until the end of the life span. It clearly shows a fragmented and sequential industry that has to change to adapt to the new way of working more simultaneously, at least for the designs, estimating and scheduling and more collaborating during the construction.

Currently, we are in transition from CAD drawings with limited information to BIM (Building Information Modeling) based in elements tied to a database that contains a lot of information that can be extracted and used in many ways.

2. BIM (BUILDING INFORMATION MODELING)

With the introduction of BIM, the coordination of the project changes drastically from sequential to simultaneous or concurrent. It implies a shift in the work environment and most likely more training would be necessary. To work simultaneously, a server (that has limited capacity) is required so that architects and engineers may work in a collaborative way (see Figure No. 1). Architects work on the 3D model design while the structural, mechanical and electrical engineers work simultaneously, saving the model in the server. The software allows them to work on their own computer while periodically updating the file on the server which simultaneously updates the engineers' files on their own computers.

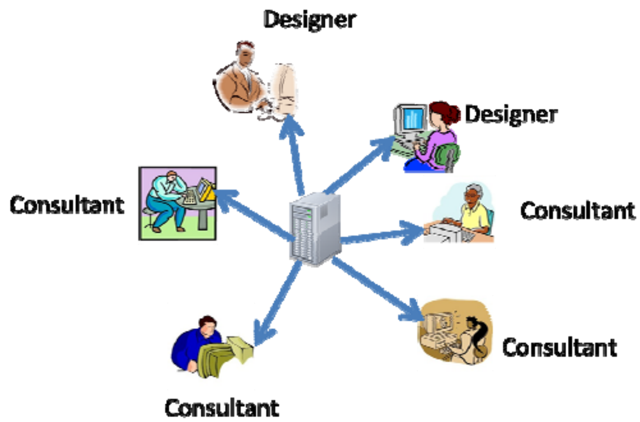

Figure 1. Server configuration (same office)

Programs used by designers today are built with a database incorporated with complete information about each item that is then complemented during the construction. It allows the information to flow directly from the designer, to the builder, to the owner and the administrator of the building after its occupancy.

3. THE CLOUD

With the cloud the computational capacity and storage capacity change drastically how teams work together. Software companies now sell services instead of software. People can buy the right to use a program instead of buying the program and sign contracts with those companies in the same way you sign contracts with internet or phone providers.

Before a design starts, owners can calculate the amount of data to be stored in the cloud and the number of people that have access to the required programs for the design and administration during the construction and after the occupancy of the building. This allows for centralized information. Instead of having fragmented information, the owner has a complete package with everything from design to construction, plus every piece of information that comes during the life of the building. It becomes the brain of the building. To help understand the concept, see Figure No. 2.

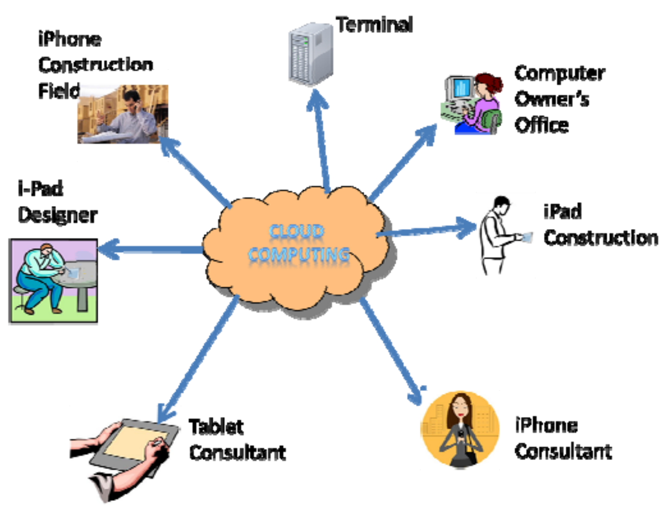

Fig 2. Cloud Computing (Remote & Mobile Devices)

Besides having a bigger capacity for storage and processing of information, the design, construction and maintenance professionals will have access to better programs and more time for simulations and performance analyses to make better decisions.

It is clear that integrated design and engineering added a significant value to the industry. It prevents delays and saves money every time there is not a need for re-designs and changes due to last minute variations as it will explains bellow.

3. CHANGES WITH THE BIM AND THE CLOUD

With the BIM environment and the unlimited capacity of computing on the cloud, many changes are coming.

Designers can evaluate different alternatives faster and with the collaboration of all of the project participants, spending less time and minimizing errors. 3D visualization of the model improves and enhances multidisciplinary communication with all the professionals involved in the design and construction. Improvements in communication of all disciplines and early involvement of contractors, subcontractors and suppliers provide better insights related to the construction process being carried out with fewer changes during the build process.

Clash detection that was introduced with BIM is an invaluable source for saving time, money, disruption and delays during the construction while waiting for changes. Errors across all disciplines during the design phase become visible at the time of clash detection, reducing cost and time after minimizing the number of requests for Information (RFI) and modifications during the construction.

Currently BIM is based in three dimensional (3D) models. The upcoming generations of BIM are based in 4D and 5D models where 4D incorporates the schedule with automatic visualization of the construction sequence and 5D incorporates the estimate. Given that all the 3D models are built in a database environment and composed by objects that represent the different elements of the building, the data of those elements can be used to simulate the construction of the project 4D BIM model and provides quantities for cost estimating known as a 5D BIM.

BIM and its rich database created an opportunity to visualize the construction process generating a physical, meaningful construction sequence of the building components. For doing the visualization, a spatial reasoning takes into account the structural construction practices, the different materials layers for finishes, and work access. Without the 3D model, the scheduler needed experience to visualize the whole construction to produce the schedule. This process is time consuming, subject to mistakes and challenging especially for young professionals. The resulting schedule is a generated list of activities with connected relationships that allows a network representation. With 3D models, activities and visualizations are linked to generate a 4D view of the model (sequence of activities with linked time).

According to Weldu and Knapp (2012), the 4D view from BIM models that we have today is the 4th generation in the evolution of automating construction schedules. The first generation was the activity-based schedule, the second was the visualization, and the third was the automated link between activities and 3D CAD models. The establishment of a data format to exchange standard drawings, document requirements, collaborative workflow and schedules will provide better standards for the industry.

To prepare an estimate, estimators digitalize the paper drawings when they come in a paper or do takeoffs from the CAD drawings. With BIM things change; a professional can extract the data (quantities and prices) from the database, but an experienced professional would be necessary, since the model does not include some requirements, for example, temporary structures or special equipment like pumps, power plants, cranes, materials and equipment lifting, winter heating and dewatering of the concrete etc.. “At a more advance stage of precise estimating (using Autocad, QTO, Innovaya, Vico, Tocoman) based on the model, cost estimating should also be linked to clash detection, constructability analysis and construction scheduling“ (Forgues, 2012).

Using the model for estimating purposes, manual takeoffs are not necessary. It can be downloaded in an Excel format, saving time for this intensive labor task that is nearly half of the whole process of estimating. Many authors agree that takeoff is half of the work, the other half is pricing. Some software programs can easily detect changes in the design when the quantities are re-imported from the model.

Due to BIM, integration of the structural and construction engineering process needs to change. The more important changes are related to efficiency in design and the construction process. Developing the structural design simultaneously with the other designers avoids the creation of a temporary structural grid, saves time and improves coordination and communication throughout the model and the team members. It also helps the team members make better decisions which prevents time consuming and costly duplication of efforts (Schulz, 2012).

Another benefit comes from the time frame for shop drawings during the construction. We are accustomed to shop drawings coming from the fabricator because in general, the structural designer pays limited attention to how the different parts or elements will be constructed. The details of the construction are defined during the shop drawings and buy out process (Tatum & Luth, 2012). One of the changes that comes from BIM is that shop drawings come directly from the 3D model instead of from the fabricator. In this way, a guarantee exists that efficiency starts with the designer, and efficiency is definitely the future of the industry.

One of the benefits of having the structural designer producing the shop drawings is that cases like the Hyatt Regency Walkway Collapse will be prevented. In this accident 113 people were killed and 186 injured when two suspended walkways collapsed in a hotel in Kansas City during the opening ceremony due that shop drawings with some drastic proposed changes were not properly revised because everybody was busy and assumed the previous person in the line had already analyzed the changes. In that case if everybody had been doing their job and the shop drawings were revised, it would not have happened.

4. GLOBAL PROJECT ORGANIZATIONS

With BIM and the cloud, the construction industry players, designers, consultants, contractors, subcontractors, suppliers, etc., come together to form a temporary consortium to carry out and manage the work. One of the firms takes the lead role to manage the project and insure that all parties carried out the project according to the terms of the contract.

This temporary consortium can easily excel in experience and knowledge given that each small company provides the new forming consortium with the best of the best. The communications channels are electronic and there is not a physical place (office) for the consortium, besides the project's trailer. Once the project is finished, the consortium ends (See figure No. 3), but the created electronic model and its database guarantees accurate data for the owner and the administrator.

Fig 3. Consortium for a project

Another benefit from the BIM and the Cloud is that various professionals can be working simultaneously in different cities or countries while communicating face to face through the computer screen and looking over the same drawings or even sharing the same screen. In this sense, it is the same of what was done in the past with the phone when they looked over some drawings they received by mail or by fax, but this time faster than before. With the communications done via internet, we can say that engineering today is more cooperative than ever.

5. WHOLE LIFE CYCLE COSTING (WLCC)

WLCC is a concept that is used in engineering and construction projects for decision making; for example, to decide about equipment that requires replacement during the life of the building. That is the case with the elevators, windows or water heaters. Unfortunately, it was against the buyers since desire for profit is the driving force behind the development of many projects. Making a line between what is beneficial for the buyer and what the builder is offering sometimes is the deciding factor. We want to optimize the resources over the life span of the building, but during the design and execution of the project only, leaving operational cost to the future owners that sometimes go to buyers with burned expenses.

The life span of a project is a concept that has been changing in the last few years due to the owners' or clients' interest in using the electronic 3D model for future facility management and administration. The life span of a project for an architect or an engineer was the one that starts with the conception of an idea to the moment the project was turned over to the owner or the client for its occupancy. Any new changes in the building were considered by the architect or the engineer as a new project with a new life span. Having a project tied to a database with information of each element is like having a body with a brain and memory that for maintenance is very important. Extending the life span of the project from the conception of an idea to the disposition of the building after its life expires creates a new dynamic and a need for a more transparent management of the WLCC. The need for replacement of components or equipment will be over the table at the negotiation time when an owner will be buying a building. Over time, ambitious builders pushed the dividing line between what is beneficial for the builders and the buyers to one side, using equipment or parts with shorter life span, moving many expenses to the maintenance. With a continuity of flowing information from construction to maintenance until the life span of the building expires, the position of the divider line will be more visible and designers will be incorporating the environmental requirement for final disposal of the building with the data provided to the owner.

6. TODAY VS. TOMORROW'S, KNOWLEDGE, SKILLS AND CURRICULUM

Usually the construction industry changes have been slow, but in the last few years the trends and changes have been accelerated. It is why we have changes that we have already started and many more coming. Changes in the curriculum was done not substituting classes, but introducing material and assignments in certain classes to change students' abilities and knowledge according to the market requirements.

Table 1 compares what we have in the construction industry today versus what we are going to have tomorrow to facilitate the identification of what skills and/or knowledge are necessary to add to the actual curriculum in The Construction Engineering & Management Technology Program at Purdue University North Central campus.

TABLE 1: TODAY VS. TOMORROW SKILLS AND KNOWLEDGE

Today: Fragmented and Consecutive Stages for Project Delivery	**Tomorrow: Integrated Project Delivery**	**Need Skills and/or Knowledge**
Design with programs not tied to a database or tied to a primitive database	Design, construction materials and maintenance tied to databases that allow predicting changes with anticipation.	• Database knowledge • Whole Life Costing
Each member is in charge of one single part of the whole project, and integration occurs in a predetermined position in time	Each member is in charge of one part, but all members work coordinately and simultaneously.	• Organizational vision to integrate all team members of the project • Organizational & management skills
3D special ability and abstraction is very important for the designer and the construction project manager who always received 2D drawings and needed to convert them in his/her imagination to 3D to find mistakes before construction starts.	3D special ability is simple today with practically no need for abstraction due to the increased capacity of the computers and better 3D programing capabilities and Clash detection.	• Design and interpretation of 3D, 4D and 5D models
Limited computational power due to the size of computer	Unlimited computational power due to the cloud.	• Computational skills
Subsequent designs. Most of the time a design from one discipline is followed by another discipline: Architectural, structural, mechanical, electrical.	Collaborative and simultaneous engineering design and construction. All professionals work simultaneously in the same model	• Team work • Communication Skills
Difficulties to run simulations due to time constraint and computers capacity	Cost, energy performance, water and air circulation can be simulated on the cloud.	• Simulations knowledge
On site construction	Manufacturing construction with the help of robots	• Manufacturing knowledge
Few assemblies on site	More assemblies on site with more complex designs.	• Assemblies knowledge
No many complexity projects	Higher levels of engineering due to the complexity of the projects.	• Engineering knowledge
Maintenance occurs completely independent from the design model. Maintenance records in paper	The owner receives the electronic model with a database tied to it, permitting a continuity prevention maintenance program thanks to the information provided in the database.	• Data Base knowledge • Whole Life Cycle Costing
No sensors used	Sensors located strategically provide performance data to enrich the database that at the same time will permit optimization strategies and better decisions.	• Decision Making • Optimization of Strategies

Previously our students were prepared for what the industry required: two dimensional (2D) models, with good foundations in design, scheduling, estimating, and structural and soils studies, along with management skills. The skills gained were disconnected due to the fact that we had a fragmented industry. Now industry requires building information modeling (BIM) based in 3D models with 4D (schedule) and 5D (estimating) integrated.

Three years ago, we started a progressive schedule of changes with faculty preparation: learning the new software for 3D-BIM modeling. We had two CAD classes in our program (2D and 3D) and one 3D modeling class focused on residential construction in the second year. It was important since we have associate and bachelor degrees.

Our first change in the curriculum was two years ago, compacting the two CAD classes into one (2D and 3D), and using the second CAD class for 3D modeling with a focus in commercial construction. In this way, students gain the descriptive geometry skills and can plug them into 2D and 3D views to aid them in visualization.

The first year teaching 3D BIM modeling, we used only the architectural and electrical design part of the software and by the second year, the faculty was able to incorporate the mechanical and structural parts. The students designed a five story building during the semester. At this point, students have not taken a structural calculation class or a mechanical and electrical systems class, but they are able to use the software and recognize many features from the program.

In Fall 2013, this particular group of students is going to take an estimating class. For the first time, quantities take offs will be coming from the 3D model instead of the 2D drawings in CAD. The additional time gained will be spent in complementing the BIM environment, the whole life cycle cost for decision making in estimating and their responsibilities with the planet and the environment. Special emphasis will be made on the importance of the Environmental Product Declaration (EPD) that is based in the analysis of the life cycle and certified products.

In Fall 2013, the same group of students is going to take electrical and mechanical systems class and because they already had the 3D BIM modeling class, we expect they will have the ability to use the software; recognize some basic elements in the building; and they will use the software for doing their assignments and especially for the final project. When this particular group of students will arrive to the structural applications class, they will be able to put together the whole structural drawings of a project they design and calculate it entirely using 3D BIM modeling. In this class students additionally prepare an estimate and schedule the project. The quantities take offs will be taken directly from the model.

Last semester (Fall 2012) a group of three senior students, who were taking structural applications class that knew about the 3D BIM class and recognized its value in their education, decided to take this spring (2013) that class to round out their knowledge before they go to the job market at the end of Spring 2013.

This spring (2013) students in their first year have an introductory construction class to gain the vocabulary of the industry and learn some aspects of its administration. In this class new topics are being introduced: environmental impact of materials, energy efficiency, emissions to air, soil and water and waste generation to start impacting the students and making them aware of their responsibilities while working for the construction industry.

With these initial changes, we expect our students to have better skills to succeed and fulfill the demand of well-prepared professionals in the construction engineering management field.

7. Conclusions

Since the whole life costing is part of the new approach, companies with high technical skilled people that are willing to create extraordinary designs with precise assemblies and predictable performance life cost will be the successful bidders. The unsuccessful bidders will be those with the present lower cost, since the life cost will be the factor determined by the performance of the project.

Caplehorn, 2012, suggests that a design incorporating construction and maintenance is “the new approach” in the industry, that in some ways is the same life cycle costing that has been around for a while with some extensions.

4D and 5D technologies are not yet mature, but they are moving in the proper direction. There are still problems in finding the proper combination or the perfect application between the software for 3D and the software for 4D and 5D.

REFERENCES

Caplehorn, Peter. (2012), *Whole Life Costing: A new Approach*. 1st. edition, Routledge, London. ISBN 978 0 415 43423 2.

Forgues, D., Jordanova, I., Valdivieso, F., and Staub-French., (2012). “Rethinking the Cost Estimating Process through 5D BIM: Case Study”**.** *Construction Research Congress 2012*. ASCE, pp. 778-786.

Schulz, Bradley, (2012). Vice-president Federal Architecture Market HNTB. “Design-build smarter and save”. Autodex BIM solutions. http://images.autodesk.com/adsk/files/hntb_customerstory.pdf. Accessed March 17, 2013.

Tatum, Clyde and Luth, Gregory., (2012).”Integrating Structural and Construction Engineering”. *Construction Research Congress 2012*. ASCE, pp.1301-1310.

Weldu, Yibrah W. and Knapp, Gerald M., (2012). “Automated Generation of 4D Building Information Models Though Spacial Reasoning”. *Construction Research Congress 2012*. ASCE, pp. 612-621.

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