Digitally integrated practices: a new paradigm in the teaching of digital media in architecture

Antonieta Angulo
Department of Architecture
aangulo@bsu.edu
Ball State University

Guillermo Vásquez de Velasco
Department of Architecture
guillermo@bsu.edu
Ball State University

Abstract

With the advent of the 21st century, the 25-year-old promise of multi-parametric modeling has re-emerged reincarnated as Building Information Modeling (BIM). Promoted by a trend toward Integrated Practices (IP), BIM can provide instrumentation for the design, representation, documentation of the projects, and the exchange of information among designers and other stakeholders. A growing number of disciplines in the design and construction industry are embracing the use of BIM and consequently the academia is addressing related training needs. This paper presents the accumulative experience of the authors over the last decade at Texas A&M University regarding digital media integration and our current plans for addressing future demands and opportunities. As a matter of introduction, the paper makes reference to early implementations of multi-parametric modeling in electronic design studios, early use of the Internet for the implementation of collaborative virtual design studios, and their evolution towards virtual multidisciplinary studios and fabrication studios that make use of BIM software. At the core, the paper explains how BIM can be a pedagogical tool for multidisciplinary integration and curricular articulation. The paper makes evident that BIM is more than a phenomena happening in the profession and something the academia must simply provide training for. The paper ends by drawing conclusions that outline how we can produce the design briefings

Resumen

Con el advenimiento del siglo XXI, la promesa sostenida por 25 años de modelación paramétrico ha vuelto a emerger encarnada en el Modelamiento de Información Constructiva (BIM por sus siglas en ingles), estimulada por la tendencia hacia una Practica Integrada (IP). BIM puede otorgar instrumentos para el diseño, representación y documentación de los proyectos, y el intercambio de información entre diseñadores y mandantes. Un número creciente de disciplinas del diseño y la industria de la construcción están abordando el uso de BIM y la universidad esta identificando necesidades consecuentes de formación en el tema. Este trabajo presenta la experiencia acumulada de los autores en la ultima década en Texas A&M University sobre integración de medios digitales y planes actuales para dirigir demandas y oportunidades futuras. Como introducción, el escrito menciona las primeras implementaciones de modelamiento multi-paramétrico en talleres de diseño digital, primeros usos de Internet para taller de diseño colaborativos, y su evolución hacia talleres virtuales multidisciplinarios y talleres de fabricación que usan software BIM. En lo principal, el texto explica como BIM puede ser una herramienta pedagógica para la integración multidisciplinaria y articulación curricular. El trabajo muestra que BIM es mas que un fenómeno profesional y algo que la universidad debe preparar. EL texto concluye como podemos producir propuestas de diseño y proyectos dirigidos hacia oportunidades de aprendizaje multidisciplinario en talleres apoyados por software BIM.

of projects especially directed toward offering multidisciplinary learning opportunities in studios instrumented by means of BIM software.

Key words: building information modeling, multi-parametric modeling, integrated practices, digital media education.

Palabras-clave: modelación de información constructiva, modelación paramétrica, prácticas integradas, enseñanza de medios digitales.

Background

The issue of integration has always been central in Architecture education. The existence of a backbone made out of a sequence of design studios in every architecture curricula, and the acknowledgement of the design studio environment as the melting pot where domain knowledge gets applied in the practice of design, are evidence of the importance of integration in architectural education. Many different methodologies have been implemented for bringing domain knowledge into the design studio. In some cases we have adopted a "push" approach that implies testing in the design studio the knowledge allegedly acquired in pre-requisite courses. In other less common cases, we have adopted a "pull" approach in which students need to research required knowledge on-demand as triggered by the design problem at hand. This was in particular the case of curricula that professed a "problem-based learning" methodology. Today, the challenge for our curricula in general and design studios in particular is that the need for integration goes beyond our disciplinary domain. We are currently called to address a growing need for multidisciplinary integration in our curricula and studios.

Computer Aided Design (CAD) technology has been perceived as a potential mean for the integration of domain knowledge in the design process. Following the lead of software applications in other design and engineering disciplines, in the late 80's it was envisioned that multi-parametric modeling software would allow the modeling, of not only the geometric parameters of building projects, but also, of a wide variety of additional parameters. In 1993, the annual conference of the Association for Computer Aided Design in Architecture (ACADIA) was hosted at the school of architecture at Texas A&M University where a prototype of Electronic Design Studio, equipped with an early generation of multi-parametric modeling software was demonstrated. More than a decade later, this paper reports on the follow-up of that and other prototypical implementations at Texas A&M University and our current approach to using BIM as the instrumental platform for the integration of multidisciplinary content in the architecture curricula and design studios.

Case studies of curriculum and multidisciplinary integration using digital resources

Three examples illustrate the gradual integration of multidisciplinary content in design studios: the electronic design studio, the virtual design studio, and the fabrication design studio.

Electronic Design Studios (The EDS / DDS case studies)

When the design studios migrated for the first time into a centralized computer lab, we used the term "Electronic Design Studio" (EDS). This brief experimental implementation at Texas A&M University took place no more than 13 years ago with 34 Silicon Graphics Indigo (SGI) computers running Alias Sonata, a 3-D modeling program with parametrically defined components. The EDS served mainly the graduate and senior undergraduate students who were trained in the use of the program at the same time that they learned how to solve design tasks.

First within the Sonata software environment, and later within the Reflex software environment students learned that in such modeling environments their design decisions had an impact that went far beyond the geometrical aspects of the building. For instance this was obvious when using the sound functions of the model. The students could compare the different sounds made by virtually breakings different kinds of glass. The students were made aware that every component or material in the model has a large number of behaviors that contribute to the multi-parametric attributes of the building being designed.

The elevated costs on hardware maintenance and the lack of acceptance of the software in the profession led to the rapid transformation of the EDS into centralized CAD ateliers where PC's and commercially available software platforms (i.e. Autodesk products) were available. The CAD ateliers or "Digital Design Studios" (DDS) run in parallel to traditional media based studios and were very successful in providing adequate visual simulation of the geometrical parameters of the projects. The students were in particular happy with the less demanding learning curve of the Autodesk products when compared with the multi-parametric software environment of the Alias products, but faculty were in particular concerned with the apparent disconnect from the physical world that DDS allowed. In many instances DDS instructors required the production of physical models in parallel to digital models in order to address this preoccupation.

In 2002 we introduced a student-owned laptop policy in our undergraduate architecture program and 4 years later this policy has made the use of computers pervasive in all our design studios. The design studio culture has changed and students make opportunistic use of all kinds of media but the use of CAD has been largely restricted to the visual simulation of the student's work. It has been only recently that CAD has move further into providing a clear bridge into the physical world through digital fabrication (Figure 1).

Figure 1. Evolution and adaptation of the studio environments: (1) Traditional design studio, (2) Paperless Electronic Design Studio, (3) Digital Design Studio, (4) Cold Station, (5) Computer laboratory for lectures, (6) Traditional and digital integration, wireless ubiquitous computing.

Virtual Design Studios (The Tex-Mex and Las Americas case studies)

Based on the infrastructure of DDS and the availability of videoconferencing facilities, following the trend of collaborative virtual design studios of the early 1990's (Wojtowicz *et al.*, 1992) we implemented our first version of virtual design studios in 1996. This studio, known as the "Tex-Mex Virtual Design Studio", run between 1996 and 1998, and articulated Mexican and American students (Vásquez de Velasco and Jimenez, 1997). The collaboration between students in Texas A&M University and La Salle University in Mexico City was a semester-long. The WWW became the virtual studio medium (web sites, e-mail, ftp, telnet, whiteboard). The video-conferencing was the technological means that allowed for face-to-face communication between participants and the accomplishment of very high levels of project development (Figure 2).

Figure 2. The Tex-Mex Virtual Design Studio Environment

Given the success of our first virtual design studios and again under the initiative of Texas A&M, a second version of virtual design studios was implemented in 1999. The "Las Americas Virtual Design Studio" (Vásquez de Velasco, 1999) has included throughout the years the participation of an average of 14 schools of architecture from Latin America. Despite the sheer size of the implementation, the studio dynamic remains the same with active participation and collaboration between international and virtual students and reviewers. For some time, the communication based on video-conferencing was limited (possible only with Mexican and Chilean partners), and relied more on web site and e-mail communications. Lately, video web cast through Internet 2 is a common practice among partners. The virtual sessions include presentations followed by reviews and debates (Figure 3).

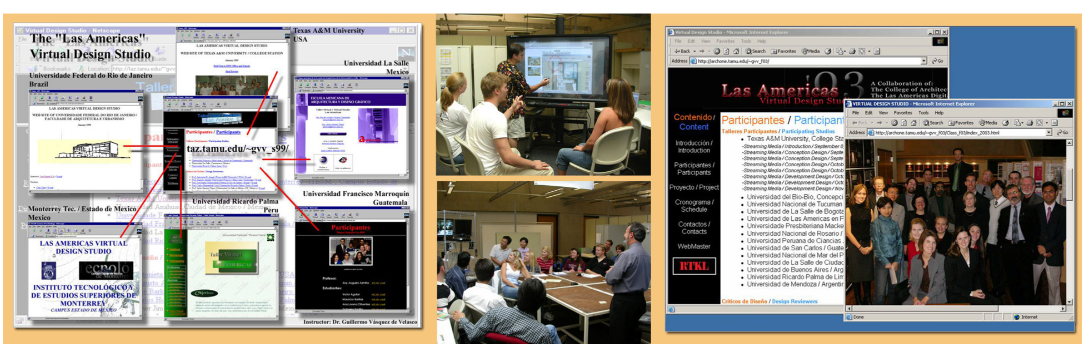

Figure 3. The Las Americas Virtual Design Studio Environment.

The Fabrication Design Studio (The laser-cutter / rapid prototyping / CNC milling machine case study)

After the acceptance of digital media in the design environment, the tendency has reverted into a more open and opportunistic use of all media, including traditional media. We have embraced the concept that the use of multiple media reinforces the project understanding (Cheng, 1995; Bermudez and King, 1998) and that translating the design project from one medium to another can lead to new directions and it would encourage refinement. The conversion among media provides opportunity for reflection and encourages the implementation of multiple cycles of creation, re-assessment, and re-definition. Among our design studios, the integration of 2-D analogue and digital media by means of flat bed scanners and printers is very common and already yields satisfactory results in terms of implementation and educational objectives.

We are also strongly promoting 3-D media integration by means of fabrication / rapid prototyping machines (RP) and 3-D laser scanners (Angulo, 2005). As a result the studio has started to migrate into the fabrication workshop in a similar way as the studios migrated into the computer laboratories some years ago. From our past experience, we expect that initially the available RP, laser-cutter, and CNC milling machines will be only used as a means to facilitate the production of scaled physical models and mock-ups, as it was in the case of computers when they were only utilized for the production of drawings. In this context, the laser cutter and CNN machines have proved to be well-accepted and regularly used by the students. It is not the same case for our RP machine (Fuse Deposition Moldering technology) where the added value of the resulting prototypes comes with a very high cost in time and money that discourages its utilization. Initial experiments using a 3-D laser scanner at the Archeological Preservation Research Laboratory at Texas A&M University have yielded positive results, especially during conceptual design stages, and validate the inclusion of shape grabbing and digitization of models in design. Following a parallel development to the one foreseen for computers in design studios, we will continue exploring the use of fabrication/scanning techniques and related methodologies as media for design and not simply as tools for the production of final models (Figure 4).

Figure 4. The College of Architecture Fabrication Facilities: (1) FDM rapid prototyping machine, (2) Laser cutter, (3) (4) Woodshop, (5) (6) (7) CNC milling machine.

In a vision of the future, our traditional design studio will also be a hybrid of computer laboratory, videoconferencing site, and fabrication workshop.

BIM as a tool for multidisciplinary integration and curricular articulation

The gradual incorporation of BIM to support integrated practices is still a process in the making and that also affects the way we incorporate BIM in our curriculum. Many look with optimism this transitional process ratifying the many promises made by BIM and IP, while others have started identifying the challenges for an optimal realization. For instance, Birx (2005) has described several advantages of BIM benefiting architectural offices, among them: better project coordination, less man-hours in the production of the project, greater productivity, better quality design and detailing, control of architectural project information, and new markets for other specialized services (cost estimating, scheduling, and imaging). While, Scheer (2005) has discussed some of the challenges that the design and building industry will face to make BIM the tool for integrated practice, among them: to solve the interoperability among computer applications, to offer enough creative freedom, to export information to fabrication tools, to define the ownership and maintenance of the BIM information among design/construction partnerships, to create new business models for firms using BIM, to modify the culture in the profession and the industry, to foster new project delivery paradigms, to enforce the application of new model verification tools, to support "what if" scenarios, and to create a sophisticated data management system at the building object level.

Since the incorporation of BIM in the IP is not yet resolved, at the academic level we also face similar issues than in the practice. We have addressed two important challenges for the use of BIM as a tool for multidisciplinary integration and curricular articulation, namely, interoperability among computer applications, and creative freedom during design stages.

The issue of interoperability and the integrated curriculum

Since 2005, we have adopted the BIM software Autodesk REVIT for our freshman digital media course (Figure 5); we expect that the students will use this or other BIM programs to produce projects more thoroughly developed and refined than with 3-D tools alone. Since the BIM tools are not necessarily more expensive or more complicated to use than more widely deployed CAD systems, the students can focus more on learning to design by integrating building systems instead of just focusing on unrelated techniques for drafting and 3-D modeling. Yet, it will be required that students learn more about how building components and systems can be integrated into the functional/formal design. They also need to learn about fabrication (manufacture), construction, and new way of communicating and collaborating with other members of the design/construction team. This training can take place within design studios and at curricular level.

Figure 5. Projects of freshman digital media course using Autodesk REVIT.

Beyond integration in the design studios, schools of architecture have been frequently asked by accreditation organizations about the possibility of providing the same level of integration at curricular level. In this case the issue is that in theory our curricula have been designed in order to facilitate that integration but in practice it is not happening. Our structure of pre-requisites is articulated with that objective but the absence of instrumental support has limited its implementation. In actuality the most common case is to find courses on environmental systems, structural systems, materials & building systems that are implemented in complete isolation between each other and in collective isolation from the design studios.

A common instrumentation environment can be a powerful resource for integration. BIM is demonstrating that potential in the articulation of multidisciplinary content in design studios and it is predictable that it can be of similar benefit at curricular level. Nevertheless, the challenge in the process of identifying the most adequate instrumentation platform for a program curriculum is very demanding due to interoperability issues.

We agree with Jonassen that no single BIM available software platform addresses all the needs. Even if one did, the likelihood that a total project team will all use the same platform is negligible and likely to remain so. Nevertheless, much integration can be achieved with combinations of currently available software and BIM technology, and cultural changes. It should be understood that the use of the term model(s) in the BIM context refers not to a single, seamless database, but to a managed set of models that usefully integrate quantity, geometry and sequence (Jonassen, 2006).

Thus, we have addressed the complex issue of interoperability among computer applications by applying a similar process than the one we used a number of years ago for deciding about the software that our CAD laboratories should offer. We will use combinations of accessible software that prove to be operational with each other. The following table illustrates the current level of interoperability that we have identified (Table 1). Based on this information and our current agreements with many of the software vendors involved we are currently designing in further detail the future subjects of our Multidisciplinary Studios.

Table 1. Interoperability among Software Applications.

BIM DEVELOPER	***AUTODESK***	***BENTLEY***	***NEMETSCHEK***	***GRAPHISOFT***	***OTHERS***
Solutions	REVIT	Microstation	Vectorworks All Plan (Europe)	Archicad	
Analysis	Green Building Studio			Green Building Studio	Architectural Data Systems, E-Specs, Specificad
Structural	Robobat, Etabs, Risafloor Risa-3d	Ram, Staad	Links to structural programs	Links to structural programs	
Mechanical, Electrical and Plumbing	MEP Revit	MEP Bentley			
Automated Estimating and Construction Management	Innovaya, USCost, Primavera	Bentley, USCost		Graphisoft Constructor	
Code Analysis					Solibri Model Checker
Facilities Management	FMDesktop	Bentley Facilities			
The NBIMS (National BIM Standard) is still being developed by the National Institute of Building Standards to create guidelines for all the software companies to integrate their data through the entire building lifecycle. The integration will be done through IFCs (Industry Foundation Classes)					
Source: H. Edward Goldberg, AIA, NCARB (Goldberg, 2006).					

The issue of creative freedom during design stages

According to Clay Risen many see parametric modeling (PM) and BIM as the future of the profession. Neither PM nor BIM is wholly new. Gehry and a handful of other architects have been using PM software for over a decade, while the firm SOM has been using a rudimentary form of BIM for almost 25 years. The two fronts are not wholly distinct: most BIM software platforms contain limited parametric capabilities, while Dassault's Digital Project, as an example of a PM platform, can deliver some BIM functions. But their relative strengths are different, and those differences are drawing more clearly the distinction between service- and design-oriented firms (Risen, 2005).

In the case of embracing the actual BIM open platform of software applications, the advantage is that we can probably address most of the content we need to integrate and in most cases it will be by using software components that the instructors of courses and studios are already familiar with. At the same time, our decision in the academic environment will probably have a good match with the kind of mainstream instrumental platform in the building environment. On the down side, it can be argued that current BIM implementations with minimal PM capabilities may still limit the creative freedom during design stages. Some may argue that the only actual limitation is the designer's creativity but in practice BIM environments are being first embraced by large firms that provide integrated services (e.g., design-built) (Figure 6).

Figure 6. Early use of BIM by SOM firm.

In the case of embracing a PM environment that attempts to be all-inclusive (e.g., may include engineering specialty modules, among other workbenches and translators) the problem is that is not as much part of the mainstream as BIM may currently be and therefore the number of industry partners you can find is likely to be substantially smaller. On the up side, a number of signature designers are using different PM platforms with substantial success and no one can question the uniqueness of the design work coming out of those offices. The PM platforms may provide the necessary creative freedom during design stages, but not without the inherent additional effort of mastering the complexity of parametric tools (Figure 7).

Figure 7. Use of PM by Digital Project Technology in the Baha'I Temple.

In academia, the decision of using a collection of BIM components or a single PM platform for the articulation of technical courses and design studios will largely depend on the nature of the school and the firms that hire their students. For the most, a set of compatible BIM software components is less expensive than a PM software platform but this may not be an issue in schools of architecture that may have free access to both kinds of instrumentation.

BIM in the Multidisciplinary Studio

The Integrated Practice Issues Forum that took place in Frank Lloyd Wright's Unity Temple in Oak Park, (Strong, 2007) was one of a series of events aimed to create a vision regarding future educational models in response to the accelerating trends of sustainability, technology, and collaboration in practice. Several interesting conclusions were stated by the different groups, among them:

1. That the students needed to experience developing design concepts within collaborative team approaches, where students for the period of a semester would take on specialist design roles.
2. That the "curriculum as required" is a format that explains the degree to which it would be studio and project based, drawing on multiple forms of expertise and providing multiple forms of experience.
3. That critically important for studio and other courses are "collaboration core competencies": ability to work successfully in interdisciplinary creative teams, write and speak effectively on professional topics, and to be skilled in the arts of negotiation and facilitation.

We have already applied similar methodologies for the implementation of design studios as a spin-off from our experience in the implementation of virtual design studios. Since 2004, we have brought together students and faculty of the Department of Architecture, the Department of Landscape Architecture & Urban Planning, and the Department of Construction Science. In our multidisciplinary studios we have addressed built environments that call for a robust interaction of disciplines. En every case these studios have counted with the participation of a multidisciplinary group of faculty that have lead their students through the protocol that a professional environment is likely to address in the execution of a similar design and construction projects.

In these implementations we have addressed subjects such as:

- Peckerwood Gardens, Texas: A repository of endangered Mexican flora that combined the functions of a botanical garden with visitor center, lodging facilities and conference center. The site included the presence of wetlands that are subjects of environmental conservation protocols and the building of the facilities was to take place in three stages combining building operations with the normal functioning of the garden and some of the facilities (Figure 8).

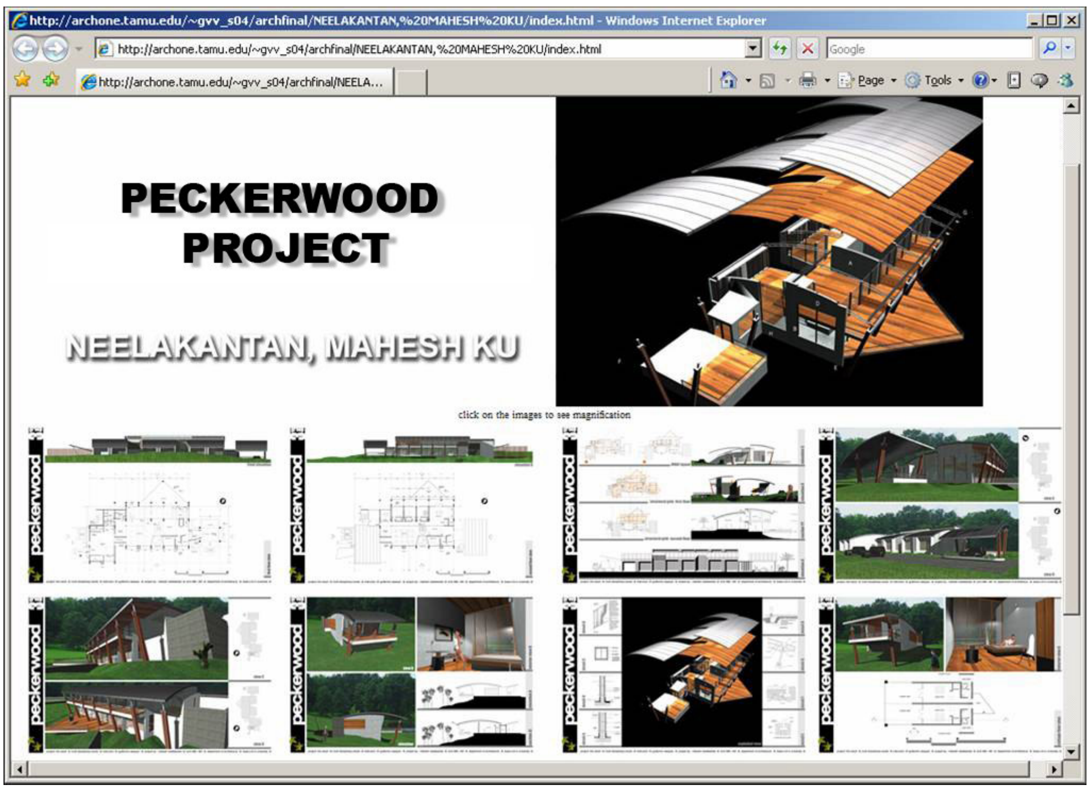

Figure 8. BIM in the Pekerwood Gardens Multidisciplinary Project.

- Hurricane Evacuation Towers, Florida: Multipurpose high-rise buildings in the Florida Keys that may be used as hurricane refuge in the eventual case of a break down of highway A1 and impossibility of implementing conventional evacuation procedures. In this case Landscape Architecture and Planning students had to address site management conditions for surge flooding and Construction Science students had to address emergency adaptive reuse of facilities that had to mutate functions and uphold hurricane wind forces.
- Texas A&M University Study Center, Costa Rica: Site planning, lodging and academic facilities for a new campus for Texas A&M University in the rain forest of Costa Rica. In this case site planning for the construction of a substantial number of buildings with minimum environmental impact was a

challenge for all the disciplines. The project currently under construction is product of the work of our students (Figure 9).

Figure 9. BIM in the Casa Verde Multidisciplinary Project.

- On instrumental terms, CAD has always provided support in the process of project documentation in these studios but during the 2006 implementation of this multidisciplinary studio some students with competency in the use of Autodesk REVIT have started to use it in combination with other BIM compatible applications. This is a new dynamic that was largely initiated by the students. Following this initiative, faculty has started discussions on how we can provide instruction on related best practices.

- Our experience in the use of BIM as instrumental support for integration in multidisciplinary studios has been very positive. The students that have used BIM as decision-making instrumental support have been able to articulate levels of content integration that are clearly superior to those achieved by students using traditional CAD instrumentation in support of process documentation. This has been in particular obvious in the articulation of design decisions, construction scheduling, and building budget.

Conclusions

Based on the authors' experience regarding implementation of design instructional environments assisted by digital tools, we may be approaching a potential shift of paradigm on the way we support knowledge integration in the design studio and across architectural curricula. The editorial line of the paper makes the following statements:

1) Architectural schools are currently called to address instructional needs at fundamental and pragmatic levels. At fundamental level students need to learn to integrate domain knowledge and multidisciplinary awareness. At pragmatic level students need to understand and know how to use digital technologies that will support their ability to integrate data, information, and knowledge in the practice of architecture.
2) We can effectively promote multidisciplinary awareness by means of multidisciplinary studios using BIM and/or PM technology as instrumentation platform. Preliminary experimentation with the use of REVIT and other BIM compatible pieces of software has been positive in the task of integrating design, construction and budget decision-making by multidisciplinary teams of students (Architecture, Landscape Architecture, Planning, and Construction Science).
3) We can effectively promote curricular integration between technical courses (Environmental Systems, Structural Systems, Material & Building Systems, and Professional Practice), Communication courses (Computer Aided Design), and Design Studios (Architectural and Multidisciplinary), using BIM and/or PM technology as instrumentation platform. Preliminary experimentation based in the teaching of related CAD tools within the design studio has been positive.
4) The question of using BIM or PM as instrumental platform for the integration of knowledge within multidisciplinary studios and across architecture curricula can be addressed as a de facto decision or as a concerted decision. In any case, the most critical issues to be address are:
    a. Institutional cost, if the software houses are not providing free access to their software.
    b. Mainstream usage by potential employers.
    c. Personal preference by individual instructors.
    d. Perceived/actual future development of the BIM / PM software environment.
5) At this time it is predictable that the mainstream of mid-size schools of architecture is likely to endorse the BIM platform. A smaller number of schools closely related with signature practices are likely to endorse the PM platform of the offices that hire their students. Finally, large schools of architecture are likely to endorse both platforms and continue to evaluate their potential future development. Texas A&M University is currently committed to the further study of both platforms.

References

ANGULO, A. 2005. Beginners' IT instructional support environment. *In:* INTERNATIONAL ACSA CONFERENCE, 93, México City, 2005. *Proceedings…* México City, p.237-243.

BERMUDEZ, J. and KING, K. 1998. Media interaction and design process: establishing a knowledge base. *In:* ACADIA CONFERENCE, 17 Québec, 1998. *Proceedings…* Québec, p. 6-25.

BIRX, G. 2005. BIM evokes revolutionary changes to architecture practice at Ayers/Saint/Gross. Available at: *http://www.aia.org/aiarchitect/thisweek05/tw1209/tw1209changeisnow.cfm,* access on 10/06/2007.

CHENG, N. 1995. By all means: multiple media in design education, multimedia and architectural disciplines. *In:* EUROPEAN ECAADE CONFERENCE, 13, Palermo, 1995. *Proceedings…* Palermo, p. 117-128.

GOLDBERG, E. 2006. How complete is the building information model? Available at: http://aec.cadalyst.com/aec/article/articleDetail.jsp?id=384117, access on 10/06/2007.

JONASSEN, J. 2006. Changing business models in BIM-driven integrated practice. *In:* AIA Report on Integrated Practice 3. Available at: http://www.aia.org/SiteObjects/files/3_Jonassen.pdf, access on 10/06/2007.

RISEN, C. 2005. The next dimension. Available at: http://www.archpaper.com/feature_articles/10_05_next_dimension.html, access on 10/06/2007.

SCHEER, D. 2005. Building information modeling: What about architecture? Available at: http://72.14.209.104/search?q=cache:2RAHyxJzWYUJ:faculty.arch.utah.edu/bim/Website%2520Info/Articles/BIM%2520What%2520About%2520Architecture.doc+Building+Information+Modeling:+What+About+Architecture%3F&hl=en&ct=clnk&cd=1&gl=us, access on 10/06/2007.

STRONG, N. 2007. Transforming design education in light of integrated practice and sustainability. Available at: http://www.aia.org/aiarchitect/thisweek07/0406/0406p_cranbrook.cfm, access on 10/06/2007.

VASQUEZ DE VELASCO, G. 1999. La red digital de investigación "Las Américas": Una herramienta de colaboración (The digital research network "Las Americas": A tool for collaboration) *In:* INTERNATIONAL SIGRADI CONFERENCE, 3, Montevideo, 1999. *Proceedings…* Montevideo, p. 384-388.

VASQUEZ DE VELASCO, G. and JIMENEZ, J. 1997. The Tex-Mex virtual design studio. *In:* INTERNATIONAL EUROPIA CONFERENCE, 6, Plzen, 1997. *Proceedings…* Plzen, p. 167-180.

WOJTOWICZ, J., DAVIDSON, J. and MITCHELL, W. 1992. Design as digital correspondence. *In:* ACADIA CONFERENCE, 11, Charleston, 1992. *Proceedings…* Charleston, p. 89-101.