A THEORETICAL MODEL FOR THE INTRODUCTION OF BIM INTO THE CURRICULUM

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ABSTRACT: The purpose of this paper is to examine the results of a research study of a theoretical model for the introduction of BIM into the curriculum of architecture and civil engineering courses in Brazil. Initially a literature review was carried out to find out the strategies that schools have adopted for BIM teaching. The functions, responsibilities and necessary skills of a competent BIM Manager have also been explored. By establishing certain criteria, it was possible to determine the kind of BIM skills that both an architect and a civil engineer must have to achieve a good performance in projects that are undertaken within this new concept. On the basis of these sets of skills, it was possible to select those that should be introduced into academic institutions and subsequently be improved in the profession. As a result of this study, a rationale is provided for planning a BIM course at three levels of comprehension.

KEY WORDS: Architecture, BIM Education, BIM skills, BIM teaching, Civil Engineering.

1. INTRODUCTION

An extensive literature review has been carried out to find out what strategies schools have adopted for BIM teaching. This study found that BIM is being introduced in several courses of the curriculum and/or as a teaching resource to enable students to understand the syllabus of the course. Moreover, it was possible to conclude that there are three levels of BIM proficiency: introductory, intermediary and advanced, and that the planning of a BIM course should pursue the goals of each one. Introductory courses should be planned to develop some of the skills of a BIM Modeler and BIM Facilitator, whereas the intermediary and advanced courses should to be planned to develop the skills of a BIM Analyst and a BIM Manager respectively (Barison and Santos 2011b).

Another study based on a literature review and job ad descriptions was carried out to identify the types, functions and responsibilities of the BIM specialists (Barison and Santos 2010) and examine the required skills of a BIM Manager (Barison and Santos 2011a). Additionally, a survey was carried out in several AEC Companies from the City of São Paulo that are implementing BIM. This study revealed that there was a current trend for BIM implementation which involved a demand for BIM specialists.

Moreover, it was possible to establish a framework for the current BIM workflow that is being used by these companies (Barison and Santos 2011c).

The aim of this study is to define desired BIM levels of competency for graduate architects and civil engineers, as well as for Post-graduation and continuous education. While focusing on the situation in Brazil, the purpose is to know what topics should be covered at each level for each audience, and in what depth.

At the outset, an attempt was made to determine the kind of BIM skills that both an architect and a civil engineer must have to achieve a good performance in projects that are undertaken on the basis of this new concept. To define these skills four criteria were established: (a) a list of the BIM competencies required by an efficient BIM Manager; (b) a framework for a BIM workflow currently used in Brazil by some AEC companies; (c) a review of texts concerned with the trends in TI for Building Construction and (d) the analysis of both the architecture and civil engineering curriculum in Brazilian universities. First of all, there is an examination of the BIM competencies required by the professionals, and following this, the question is raised of what competencies should be taught in the academic world to bring about improvements in the profession.

2. BIM COMPETENCIES REQUIRED BY PROFESSIONALS

On the basis of the framework outlined by Barison and Santos (2011c) for the current BIM workflow used by some AEC companies in Brazil, the person responsible for supervising the BIM process is the BIM Project Manager who works in owner organizations, which in some cases are construction companies, and may be an architect or civil engineer, as shown in Figure 1.

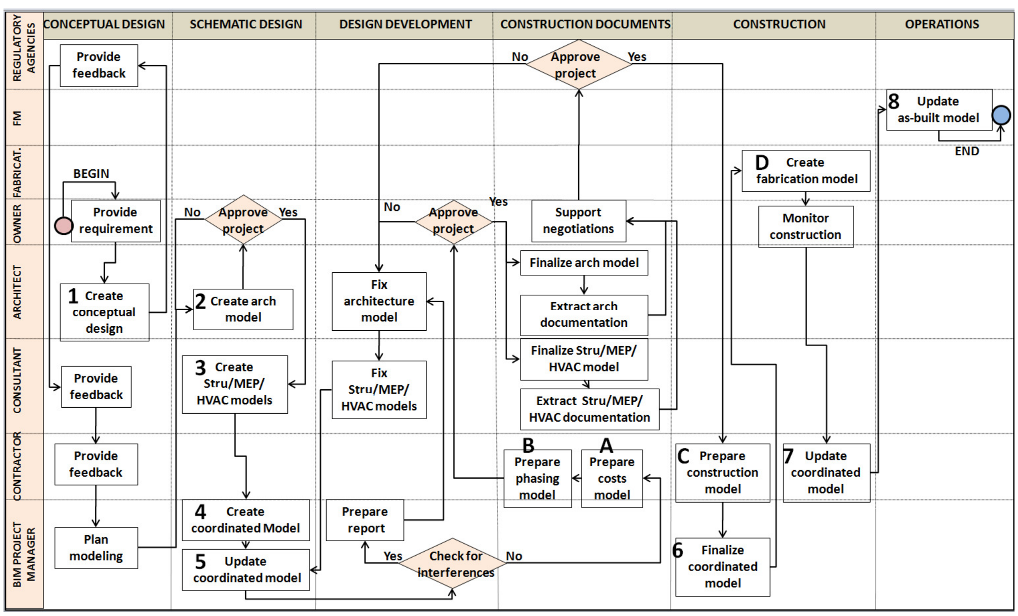

Figure 1 – Current BIM workflow used in Brazil by some AEC companies.

2.1 BIM competencies required by an Architect

In the experience of BIM implementation reported by Bastos et al. (2011), the architect creates the conceptual design which, when completed, is sent to both the

BIM Project Manager and the MEP/HVAC Consultant (Stage 1, Figure 1). The BIM Project Manager studies the conceptual design to determine what information must be contained in the families, creates a basic structure of all the subject-areas and builds the ‘families’, which serve as a basis for use by other Model Managers. The Project Model Manager (architecture) creates the architectural model, divides it into several parts (foundation, floor type, facade, etc.) and creates ‘Edition’ and ‘Completed’ models (Stage 2, Figure 1).

However, in an ideal BIM process, before starting the conceptual design, the architect has to discuss with the consultants and the contractor what will be the technology adopted for the construction, the construction process, the building and technical details and the construction sequence. Before carrying out these activities, the architect must have a basic knowledge of other disciplines (MEP, structure, energy and construction), construction drawings, specifications, field experience and extraction of quantities from BIM. When interacting with the agents, it is essential for the architect to have an understanding of interpersonal teamwork and, basic communication skills, as well as a knowledge of communication and collaboration tools (Barison and Santos, 2011a).

Analysis of other aspects of the BIM model, such as energy and water consumption, the use of natural ventilation and simulations of the incidence of solar radiation, are new responsibilities for the architect. However, conducting this kind of analysis requires a good knowledge of the following: construction technologies and their influence on the thermal performance of the building, the pressure distributions (wind and air) on the building envelope and how to interpret graphs, tables and equations (Freire and Amorim 2011). In addition, when the analysis and model simulations are carried out by the consultants, the architect must have the ability to handle the input and output geometry data from the model that is needed to analysis the software.

The creation of the architectural BIM model must conform to the BIM standard of the firm and to be in accordance with the *Level of Detail* (LoD) that is pre-determined by the BIM Project Manager. These activities require the architect to have a knowledge of how to model architectural components, libraries, BIM standards, templates and LoD. The architect must also have basic management skills to be able to design technology or provide technical support for architectural modeling work (Barison and Santos, 2011a) and depending on the size of the office, must also provide in-house training sessions and prepare learning materials on BIM tools and applications (Barison and Santos, 2010). Considerable personal qualities (prioritization and commitment) and self-management (organization and time management) are needed to carry out these activities. Moreover, it is essential for the architect to have computational capabilities, as well as the skills in BIM tools and applications used in architectural design (Barison and Santos, 2011a).

When completed, the architectural BIM model is sent to the MEP/HVAC consultants so that they can develop their BIM models (Stage 3, Figure 1). During the BIM coordination process, it is often necessary to check the quality of the models and then adjust it accordingly. This means that the architect must have a knowledge of BIM concepts, clash detection, coordination processes and BIM workflow. All these skills and knowledge will be necessary for the architect to take on the task of coordinating the BIM processes.

Additionally, adopting innovative approaches for architectural digital design using BIM, requires the architect to acquire a new set of skills and knowledge. This includes the following: a high degree of skill in generative and 3D parametric modelling, understanding complex geometry/systems and its behavior, programming language skills, showing a particular interest in software development, scripting/routines in CAD/BIM tools and applications (Ceccato 2011, Hesselgren and Medjdoub 2011) and an ability to create unique visualization deliverables such as stereoscopic 3D renderings, virtual/augmented reality, or animations. However, as Whitehead et al. (2011) observe, it is also essential to have the ability to apply these computer skills in the context of an actual construction. Other requirements may include a knowledge of the actual capacity of production with software, applications and equipment for digital prototyping applied to the production of models, prototypes and the manufacture of non-standard and customized elements (Pupo 2011).

2.2 BIM competencies required for a Civil Engineer

Civil engineers must have interpersonal skills of leadership and teamwork, personal self-management qualities, clear objectives and an independent way of learning, to be able to supervise the structural, MEP and/or HVAC systems modeling.

Apart from modeling, the consultants also carry out analysis and simulations based on BIM, such as, structural, pressurization, lighting, acoustics, temperature and energy analysis. These activities require the civil engineer to have skills in the use of BIM tools and applications. The MEP engineer must know how to use climatic input data, and information about the thermal properties of building components and materials. The analysis tools for thermal energy do not usually allow easy visualization and understanding and show the results through graphs and tables. Thus, it is essential for a MEP engineer to know how to interpret graphs and have spatial visualization skills (Freire and Amorim 2011). Another requirement includes being able to recognize actual pieces of equipment, knowing how a building is constructed, even being able to recognize what the acronyms and abbreviations mean, although the most important skill is the use of a BIM tool (Tebbe 2011).

When working as a BIM Project Manager, the civil engineer should have a knowledge of the following: the technology needed for collaborative systems, the concepts and processes involved in BIM coordination, BIM workflow and clash detection (Barison and Santos, 2011a). A knowledge of the requirements of each platform is needed to carry out the transference of files to ensure that only the information that is necessary for the completion of the work is transferred. For this reason, it is essential to have a knowledge of interoperability and clearly defined objectives, that are focused on the task. Combining and updating the partial models, data and project documents in a new coordinated way (Stage 4, Figure 1) requires critical and systemic thinking and an ability to manipulate and use BIM applications and clash detection tools. This requires skills in employing tools and knowing the features of each subsystem (structure, HVAC, MEP and fire) to determine the order in which the clash detection should be carried out.

Other activities of the coordination meetings such as the definition of standards for the quality control of the models, delegating responsibilities and ensuring that the coordination tasks are carried out (Stage 5, Figure 1), will require a civil engineer, interpersonal skills of leadership and management, as well as empathy (Livingston

2011). According to Martin (2011), the coordination meetings must be synchronized with the schedule for the construction and the models must be checked before the start of the meetings. These activities require a civil engineer with organizational skills.

The development of the cost, phase and construction models (Stages A, B and C, Figure 1) requires skills in basic management, the use of tools for cost estimates, a construction schedule, site logistics and safety planning. The cost model may be connected with Enterprise Resource Planning (ERP) tools, and this activity requires the civil engineer to have a knowledge of the use of this tool and its application to the BIM model.

Civil engineers must interact with suppliers, subcontractors and vendors and manage the bidding process, purchasing, manufacturing, while also establishing communication between the regulatory agencies and the project team (Stage 6, Figure 1). To fulfill these tasks, this professional must have interpersonal networking skills, that is, an ability to identify, create and maintain contacts with various stakeholders. In addition, he/she must have some knowledge of the construction and manufacturing process, contracts, BIM standards, construction drawings and materials specifications. As Integrated Project Delivery and Lean Construction are new paradigms for BIM construction, it is also desirable for the civil engineer to understand these new concepts.

A civil engineer will need skills in the visualization and manipulation of BIM tools to be able to assist the field staff in visualizing the model. Similarly, he/she will need to be able to update the model during the construction phase so that the model can become the 'As-Built' model and also to help facilities managers extract data from the model (Stages 7 and 8, Figure 1).

Working as a BIM Construction Manager or Construction Officer in General Contractor and Subcontractor firms, the civil engineer will need skills that allow him to give support to software/hardware, setting up training courses and teaching materials to the employees. In addition to these skills, the civil engineer should be motivated by BIM, have initiative and always be willing to travel to the branch offices when necessary. As well as this he/she should be a team player, who is self-driven and, above all, is willing to introduce changes (Barison and Santos, 2011a).

Additionally, the civil engineer should be able to create a model from points cloud data so that he can work with new technologies for civil construction such as the use of digital cameras in the field to check if the construction is in accordance with the scheduling and contract specifications and then compare it with original BIM (Bhatla and Leite 2011).

3. WHAT BIM COMPETENCIES MUST BE TAUGHT?

Behavioral skills such as cognition, emotion, interpersonal relationships and motivation are those which most influence professional success. However, training sessions in these skills are becoming increasingly difficult to implement and thus it is very important for employers to hire professionals who already have these kinds of skills. However, when recruiting new staff, technical skills are more easily identified (Hoff 2010).

Thus, the academic institution should teach behavioral skills and set up courses on some technical skills, which may be further refined in the post-graduate stage. Whitehead et al. (2011), for example, claim that to work with the Specialist Modelling Group (SMG) at Foster and Partners all that is needed is to be an architect and have experience in teamwork. When joining the SMG group, an architect spends at least two years absorbing the culture, learning different forms of teamwork and developing skills. Hence, an architectural curriculum should focus on improving students´ ability to collaborate with their peers. Moreover, the universities are the ideal place for them to practice interpersonal leadership and basic communication skills (Becker, Jaselskis and McDermott 2011).

3.1 BIM competencies naturally acquired in the academic institution

The architecture programs tend to instil the basic skills of non-verbal (graphic) communication, the use of the computer and tools used in architectural design. Other skills such as cognition, research (critical and analytical thinking), interpersonal (teamwork) and interpreting graphs, tables and formulas are also taught. The architecture students acquire knowledge in architectural design, construction drawing and materials specifications. They also become familiar with other disciplines (MEP, structure and energy) and learn about lean construction processes and construction techniques. The construction of physics models are usually taught in specific labs which have to be equipped with laser cutters, milling machines and 3D printers for rapid prototyping. However, the curriculum of Brazilian architecture programs does not include specific Project Management courses (Amorim et al. 2008). This topic is usually taught in post-graduate or *Master in Business Administration* (MBA) courses.

Civil engineer programs develop the basic skills of communication (oral, writing and graphic), cognition, research (analytical and critical thinking), 3D visualization and interpersonal relationships (teamwork). The students acquire knowledge in CAD, programming language, graphic representation (sketching and construction drawing), the construction and manufacturing process, business, contract language and professional standards. Although topics such as business process, resource management (financial and human) and marketing are covered in Project Management courses, these areas are explored in greater depth in post-graduate level or *Master in Business Administration* (MBA) courses.

3.2 BIM skills that should be taught in academic institutions

An architecture curriculum should focus on the behavioral competencies of a BIM Manager such as basic communication, interpersonal and personal skills and attitudes. Interpersonal skills can be developed when students are engaged in real projects (Jones et al. 2011), as for example in an Interdisciplinary/Collaborative Design Studio course. They should also focus on some technical competencies such as the following: a knowledge of BIM concepts, BIM workflow, clash detection, the use of an architectural BIM tool, some applications used in the early stages of design and the techniques used in the new approaches to digital design. These competencies may be necessary when new staff are being recruited.

Generative modeling tools should also be explored to enable the students to experience new architecture forms and surfaces. According to Hesselgren and Medjdoub (2011), geometry and programming language skills, and understanding the complex systems and their behavior are pre-requisites that are not taught in all schools. In Brazilian schools of architecture, for example, courses that teach computational concepts are rarely compulsory and there are few students who are interested in learning a programming language. However, there are some types of software that can be used to introduce computational concepts for student without previous knowledge of programming language (Celani and Vaz 2011). These skills should be developed at the beginning of the programs (freshman or sophomore). Xavier de Kestelier, for example, teaches generative components, digital prototyping and scripting to sophomore students (Whitehead et al. 2011).

Skills to extract quantities and documentation from architectural BIM tools may be acquired in Design Studio courses. The automated manufacture of building components from BIM can be taught through case studies, since the school labs do not have the necessary equipment.

Similarly, a civil engineering curriculum should also focus on behavioral competencies and teach some of the technical skills of a BIM Manager. The interpersonal skill of empathy and leadership can be acquired in teamwork with students from others courses such as architecture. According to Jerald (2009), research has shown that some student activities and competitions can help to improve the interpersonal leadership skills. The personal skills of self-management, setting goals, and independent learning can be acquired through being engaged in real projects.

3D visualization, extraction of quantities and documents from BIM tools and the use of cost-estimating tools are some of the skills that can be taught in school and improved in the profession. However, it is essential for students to be introduced to a BIM tool, some applications of analysis/simulations and clash detection tool so that they can learn how to plan their modeling. Other important knowledge is as follows: construction of a schedule, 4D simulation, site logistics and safety planning construction and using BIM tools, as well as new survey techniques such as points cloud and monitoring with a digital camera.

The degree of motivation to learn BIM and teamwork and the willingness to teach others can be evaluated while the architecture and civil engineering students are carrying out their projects. BIM coordination processes, BIM workflow, BIM concepts, clash detection, collaborative systems and interoperability form a basic core of knowledge that will assist students in acquiring these skills.

3.3 BIM competencies that can be improved in the profession

Software/hardware support, training and the preparation of learning materials, are skills that are naturally acquired in professional practice, as well as the ability to handle geometry data flow between the architecture model and several analytical tools. It is difficult for schools to focus on these skills because generally they lack the financial means to acquire several of the necessary tools with the result that the faculty is not trained to teach some of the applications.

Functional management skills are also better combined with professional experience since the reason the academic institutions introduce the students to the concepts might be because of a lack of resources, especially regarding an appropriate environment, software and applications. Certain types of infrastructure are needed, for example, to simulate the real environment of a 'big room'. Even if the school is able to simulate a similar environment, the dynamics of interaction will be different from professional practice due to the large number of students and short time available in the courses to teach this subject. Furthermore, some applications are unavailable for schools, such as ERP software.

4. CONCLUSIONS

In this paper, there has been a discussion of what BIM architectural and civil engineering skills should be taught in academic institutions at graduate level, while taking account of the nature of BIM implementation in the context of Brazil.

In general, the curriculum caters for some skills but does not address the question of what attitudes should be required of a BIM Manager. Both programs focus on creative, lateral, critical and systemic thinking, teamwork, the use of computers, interpretation of tables, graphs and formulas and a knowledge of geometry, construction processes, documentation, drawings, standards and materials. While the architecture student becomes familiar with other subject areas such as the thermal performance of a building, civil engineering students are introduced to construction management and learn about issues like construction business and contracts. While engineering programs concentrate on basic skills in written and oral communication, architecture programs teach basic skills in graphical communication and the use of tools for architectural projects.

Both civil engineering and architecture students should learn behavioral skills (interpersonal and personal) and be introduced to some technical skills such as the visualization of the model, 3D parametric modeling (creation of components, libraries and templates), extraction of quantities and documentation from BIM, the use of the BIM tools and applications commonly used in their subject-areas and communication/collaboration tools. These skills require a knowledge of BIM concepts, 3D parametric design, standards, BIM coordination, clash detection and BIM workflow.

However, an architecture curriculum should lay greater emphasis on new processes and techniques of digital design and computational concepts. It should also focus on the initial analysis of the model and engineering subjects that are usually not addressed, such as schedules, costs and constructability. Written and oral communication skills should also be developed, together with the use of BIM applications for initial analysis, the use of generative modeling tools, scripting, digital prototyping, digital manufacturing, programming language, and technical criteria for certifying production.

At the same time, a civil engineering curriculum should focus more on creating models and carrying out engineering analysis/simulation and planning for modeling. It should also teach skills in graphic communication, networking and the use of tools for clash detection, cost estimates, 4D simulation, site logistics and construction safety planning. Other new techniques could also be taught such as construction monitoring by using digital cameras and cloud points. However, training on the job is needed to enable both an architect and a civil engineer to understand the complexity of the role of a BIM Manager, together with specialized courses, certification in centers for BIM competencies and probationary periods for new BIM Managers.

ACKNOWLEDGEMENTS

The first author would like to express her gratitude to CAPES for partially funding this research (case 047/2008) and also to Cristina Belderrain for her helpful comments and suggestions on BPMN. The second author is grateful to CNPq for partially funding this research.

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