DESIGN COORDINATION WITH BUILDING INFORMATION MODELING: A CASE STUDY

Renata Heloisa Tonissi Buschinelli Goes, MSc / Architect, rhtbg@yahoo.com
Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT), São Paulo, Brazil
Eduardo Toledo Santos, PhD/ Assistant Professor, eduardo.toledo@poli.usp.br
Construction Engineering Dept., Escola Politécnica of the University of São Paulo (USP), São Paulo, Brazil

ABSTRACT

Despite some isolated initiatives using 3D CAD or BIM (Building Information Modeling) tools, project processes in the Brazilian AEC industry are still essentially developed using 2D technology, especially in the design development phases. There is evidence in the literature that 2D representations are prone to difficult-to-detect design errors and representation mistakes. BIM is an emerging paradigm based on object oriented, parameterized 3D CAD tools that promises an even better performance in design coordination processes than standard 3D CAD. This work aims to identify the potential for using BIM tools in the design coordination process as a more effective alternative to two-dimensional methods (abstraction and overlaying of drawings for interference checks and clash detection among different design disciplines). The research was based on the execution of a case study involving a complex residential building. Its design was developed as usual, with 2D CAD, as was its coordination process, by professional firms hired by the owner. Afterwards, using the same documents provided to the coordination firm, the first author independently developed the architectural, structural, plumbing, and HVAC BIM models for the standard floor plan of the building, simulating both the Schematic Design (SD) and the Design Development (DD) phases. During and after this process, detected interferences and information errors or omissions were documented in order to be compared with those reported in the traditional process of design coordination. The comparative analysis of both reports in this case study showed that the methodology with BIM detected 75% more design interferences and inconsistencies than the 2D-CAD supported method. This was partly due to the easier visualization of the virtual model, and to the software features for automating interference checks. On the other hand, the analysis of the interferences found in both processes demonstrated that the modeling procedure alone can affect design perception and evaluation, allowing the detection of a greater number of incompatibilities during the process.

Keywords: Design Coordination, BIM, Clash Detection, Case study

1. INTRODUCTION

Considered one of the most important economic activities in Brazil, having responded for 9.2% of its Gross Domestic Product (GDP) in 2009 (FIESP 2010), national AEC industry is also known for its low productivity when compared to that of other countries or even to other segments of the national industry (FIESP 2008). One reason for this situation is the high rate of wastage in construction (Peralta 2002), which is caused, among other reasons, by design flaws (Cambiaghi 1992).

In the current landscape of high capital investments in the country, modernization of the sector aiming to improve design quality and productivity is urgent. Melhado (1993) argues that it is vital to have consistency, organization and technology integration in the communication and transmission of design information for execution. In this sense, design coordination is a subject of interest and relevance, directly affecting the quality of the final design and construction by reducing rework, and wastages of material and time. Studies on the sector, such as the *Strategic Plan for Science, Technology and Innovation in the Technology Sector of the Built Environment with an Emphasis in Residential Construction*, confirm that investments in the design phases have the potential to reduce costs in production, and that the use of three-dimensional models (Santos and Ferreira 2008), and BIM (Building Information Modeling) technologies (Eastman et al. 2008) can make the design process more efficient. According to Ferreira (2007), this process is still done from the juxtaposition of (electronic) drawings, showing many limitations due to two-dimensional representations (Shih 1996). Traditional 2D paper-based design coordination is an often inefficiently slow process, prone to design mistakes and conflicts which have to be resolved during construction, according to Staub-French and Khanzode (2006), who affirm that three-dimensional design coordination allows project teams to integrate their designs and identify conflicts more efficiently.

In Brazil, the two-dimensional CAD is still the most common tool for design development, having documentation as a final goal, representing the technical content of every discipline. That results in fragmented information, according to Ferreira (2007). Although the use of 3D models is growing nationally (Souza et al. 2009), there are few design firms exploring the potential of virtual models for project development, using concepts such as BIM.

BIM presents the possibility of integrating 3D geometry with information about components, having the potential to provide better visualization, increased collaboration among project teams and a significant improvement in the comprehension of the project development as a whole.

However, in general, as available as 3D technology is and as interesting and necessary it may be to the industry, it does not translate into effective and appropriate use by the AEC industry professionals in Brazil yet (Ferreira 2007). The construction industry, however, has shown signs of change within that context, as buildings become more complex, the market more demanding, and quality standards more stringent, increasingly requiring resource optimization and technical analyses on quality and sustainability performances to ensure the durability and efficiency of the building.

2. DESIGN COORDINATION

According to Melhado (2005), design coordination is the activity that integrates designs from all disciplines in order to achieve standards of total quality control of the work. In design coordination, it is usual to overlay projects from different disciplines, in order to evaluate possible effects and problems to be solved. The design coordination process usually starts after the completion of the conceptual design and preliminary definition of the building systems (Staub-French and Khanzode 2006), a sort of final review where possible errors can be detected. According to Rodriguez and Heineck (2003), the process should occur at each stage of the project, i.e., at concept design, schematic design and design development, seeking the overall integration of solutions and verification of its geometric interferences. The sooner it is developed, the more efficient the activity of design coordination is.

According to Manso (2006), this activity should be a responsibility of the designers of all disciplines, as well as construction managers and clients, in order not to overload the project coordinator. Thus, the project would be the result of different, yet integrated designs, focusing not only on the project documentation and representation, but mainly on the project itself, and its information.

Another factor that may cause failures, rework and significant costs for both designers and developers and also for customers, is the lack or delay in structural/constructive decision making, or on those regarding materials and costs, affecting negatively the quality of the final product (Melhado 2005).

3. TECHNOLOGIES USED IN DESIGN COORDINATION

To understand the concept of three-dimensionality assisting design coordination, it is necessary to define the systems currently used in project development. CAD (Computer Aided Design) systems are computer-assisted tools for vector graphics or geometry representation. However, going beyond the traditional design methods on the drawing board, such systems using two-dimensional (2D) or three-dimensional (3D) representations have functions that streamline some activities for the designer, such as area and volume calculations, properties and integrated information, which facilitate the process of decision making (Ferreira 2007). CAD is any project activity that involves the effective use of interactive computer graphics to create, modify, analyze and document engineering projects (Groover 2001).

CAD began to be applied in the construction industry nearly 25 years ago, increasing productivity and market competitiveness. Nowadays, the use of information models and virtual buildings in project development can bring changes to design firms' strategies, because this system requires new ways of thinking and organizing the project and their professional teams, demanding greater investments in equipment and training.

3.1. Computer Aided Design in two dimensions (2D CAD)

The two-dimensional graphical representation for project development consists in the production of floor plans, sections and façades, not only for analysis, but also as the final product. As in a traditional process, with no use of a computer, the information is recorded as a 2D representation through a mental process of abstraction and memorization by the designer. According to Ferreira (2007), although it is possible to introduce some automation into the 2D CAD process, the final result is the reduction of all the information and volumetric data to an abstract representation.

Ferreira (2007) states that, today, the two-dimensional representation is necessary as a final synthesis of design solutions. However, what would be a process result is used as a means for problem identification, analysis and solution. According to Santos and Ferreira (2008), the 2D representation should be the summary of the result of the development of a project (documentation), not the only analysis tool during the process. The same authors identified the following limitations of 2D representations, which they considered inherent to the system, according to Table 1:

Table 1– Characteristics of the 2D representation that can lead to analysis problems in the design process. (Santos and Ferreira 2008).

2D DEFICIENCY	DESCRIPTION
Ambiguity	The same representation may be interpreted in different ways.
Symbolism	A component is represented by a symbol whose dimensions are not related to the object it represents.
Omission	Information is omitted from the drawing as a way to make it cleaner or because such information could be presumed.
Simplification	A representation is a simplification of the object it stands for. It is similar to Symbolism, but its shape preserves some true dimensions (like pipes represented by single lines).
Fragmentation	Occurs when the information necessary to fully understand the geometry is scattered in several separated views (sometimes even in different sheets) like floor plans and sectional views.

3.2. Computer Aided Design in three dimensions (3D CAD)

CAD systems can also generate three-dimensional objects using composition of solids and surfaces. A model made in a 3D CAD tool is a purely geometric representation of elements (Tse et al. 2005). Plans, sections and elevations can be drawn, but they must be edited and two-dimensional information inserted to be completed. The ability of CAD systems to model three-dimensional objects allows the designer to create and edit the geometric model or its components, from primitive objects available in the system (Groover 2001). But according to Tse et al. (2005), object-based tools are more sophisticated and appropriate for modeling buildings, since they also have the ability to load information into the three-dimensional models.

Three-dimensional CAD is still not largely used in Brazil, especially for the purpose of design development (Souza et al. 2009). Among the reasons leading to this low use of 3D CAD are the working methods of each company and the fact that many professionals do not know how to use this tool yet.

3.3. Building Information Modeling (BIM)

For Eastman et al. (2008, p.13), BIM is "a modeling technology and an associated group of processes to produce, communicate, and analyze building models". According to those authors, BIM models are characterized by:

- Components of the building, represented by intelligent objects that know what they are, and that may be associated with attributes and graphics data, and parametric rules.
- Components that contain data describing their behavior and that can be used in other applications for performance analysis and budgeting, for example.
- Consistent and non-redundant data to allow automatic changes of various views of the object.
- Coordinated data as all views are extracted from the same model.

The difference between a BIM model and a conventional 3D model is that the latter is only a three-dimensional geometric representation of the building while a BIM is organized as a prototype of the building, in terms of floors, spaces, walls, doors, windows, among other elements, including a wide range of information associated with each of these components through parametric relationships. The BIM model can usually be seen in 3D, but the model also includes information used by other analysis applications, such as cost estimation, simulation of energy consumption, natural lighting, etc. (General Services Administration 2007). Although both systems enable the generation of two-dimensional drawings from three-dimensional models, a BIM model allows the automatic generation of plants and views complete with two-dimensional symbolisms, which allow manual editing if needed (Eastman et al. 2008), while the latter requires manual editing of some representations to be standards-compliant (Ferreira 2007).

4. CASE STUDY

The conducted case study aimed to compare the design coordination process using a BIM tool with the traditional 2D procedure, simulating the process of developing a complete building information model (architecture, structure and selected building systems), in two different projects stages (Schematic Design and Design Development). The chosen project was a complex residential building, and its designs had been previously coordinated with 2D methodology, having its conflicts and interferences registered. Then, independently, the BIM models of the standard-floor were prepared, including the architectural design, structure, plumbing and air conditioning, for both design phases. The models were coordinated into a single integrated model. An interference report was prepared for each design phase in order to produce a quantitative and qualitative comparison between the problems detected with both methods (BIM and 2D).

This is considered a complex project because the design has some unusual characteristics for the local market: the standard floor has two stores with 4 apartments each, and two double-height lofts, resulting in 10 apartments for each standard floor (as seen in Figures 1 and 2).

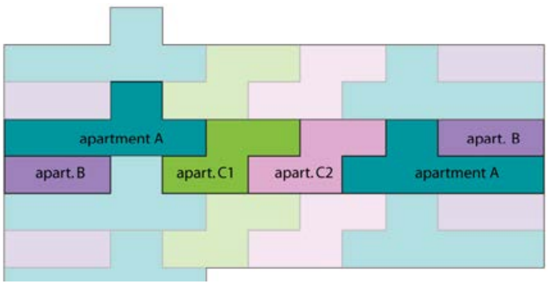

Figure 1 – Schematic section of standard double-height floor (not to scale).

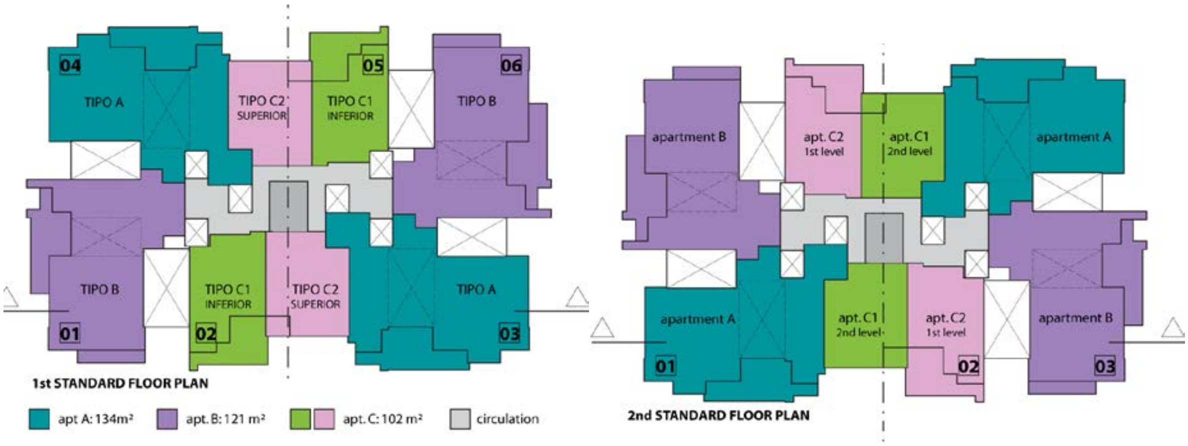

Figure 2 - Diagram of standard floor plan: lower (left) and upper (right) levels (not to scale).

4.1. Development of the Building Information Models

The office that provided the project for this case study was hired as a consultant to conduct the reports for the design coordination process including architecture, structure, plumbing and air conditioning designs, among other disciplines. Simulating the standard design sequence, the architectural design was the first to be modeled. Next, structure, plumbing and HVAC models were developed. The production process of BIM models began with the schematic designs, and it was found that the available detail was not sufficient to complete the modeling of the standard floor. In the design development phase, although there was more data to be inserted, the execution time was 75% shorter than the time taken for modeling the schematic design phase model. Changes in dimensions and families were simple and needed only once, while the information in all other views was automatically updated.

4.1.1. Architectural BIM Model

In general, the information available in the schematic design (SD) drawings had some shortcomings for the development of a complete BIM model. Due to the complexity of the project, it lacked information and complete drawings (sections). In the design development phase, much information was inherited from the former definitions, while not explicitly specified in the project. For a design coordination evaluation and especially for building an information model, there were many missing pieces of information.

The deficit of information in the design may be due to the short deadlines for project development determined by real estate market. However, with insufficient information, decisions involving other disciplines may generate delays and incompatibilities, demanding future rework. In the schematic design phase, this situation is understandable, given that decisions are still being made, but that also happening at the end of the design development phase makes it a problematic situation. The final architectural building model is illustrated in Figure 3 below.

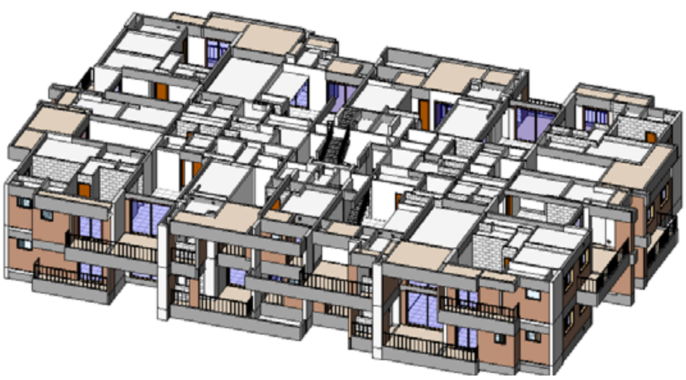

Figure 3 - Architectural Building Information Model after Design Development phase.

4.1.2. Structural BIM Model

In the Schematic Design phase, the project was very incomplete, and did not specify the levels of slabs and beams. In the Design Development phase, although data was more complete, there was still deficiencies in information that challenged the model construction. The drilling in structure needed by plumbing, electrical and air conditioning systems had not yet been provided in the structural design drawings, neither in SD nor in the DD phase. When adding the holes in the structure, some inconsistencies were found, such as big holes that split the beam into two parts (shown in Figure 4). In other cases, although not visually indicating problems, there was an assessment that the quantity of holes could potentially compromise the integrity of the structure.

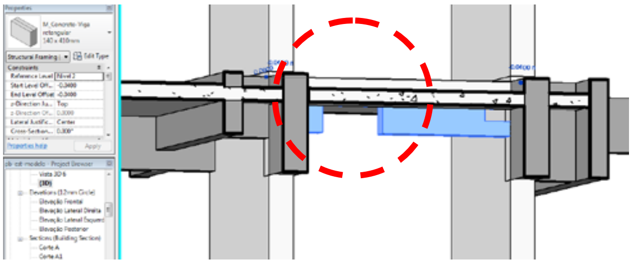

Figure 4 - Hole inferred from plumbing design was larger than the beam itself (SD)

4.1.3. Plumbing BIM Model

The plumbing model presented major obstacles for its implementation. Revit MEP is a North-American software, and is not adapted to the standards and norms of Brazilian building. This has previously been identified by the study of Souza et al. (2009) as one of the five main barriers to implementation of BIM in Brazil. Revit MEP software offers automatic plumbing solutions that are not based on standards and components available in the Brazilian market.

Thus, the construction of the plumbing model for the case study took place with a laborious approach, demanding manual assembly of pipes, and the creation of new families of components to meet design specifications and to compose connected systems (e.g., siphon drain with parametric height dimension, as illustrated in Figure 5).

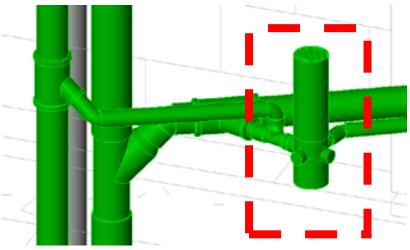

Figure 5 - Drain family produced for the project.

The lack of needed families in design tools can be seen as a problem for the implementation of BIM, since the development of component families requires specific software training. Without the production of these new families, it wouldn't have been possible to generate an efficient plumbing system that corresponded closely to the design drawn up in 2D CAD. Another aspect that challenged the model execution was the lack of information. Although the plumbing schematic designs contained more detail and information than others, they were often contradictory (e.g. the height of pipes). For reasons of simplicity and symbolism, the hot and cold water pipes always seem to be on the same level, which is not enabled by the specified drilling, hindering the proper positioning of pipes and the correct quantity take off for these materials.

4.1.4. HVAC BIM Model

In both SD and DD phases, levels of exhaustion ducts, pipes and drains were almost never specified for the drilling in concrete beams, which hindered the release of these components in the model, making it difficult to prevent the holes from compromising the structure. Despite the lack of data for the levels, it was possible to identify some interferences such as the coexistence of HVAC ducts and plumbing pipes the in the same space. It was also detected the need for lowering some plaster ceilings and for creating new ones in some rooms were ducts run. The air conditioning system design presented the most lack of data among the studied trades. However, by analyzing the model, it was possible to predict that, because of this lack of information, there would be further interferences, especially with the structure and plumbing. Three-dimensional visualization would be essential for its solution.

4.2. Interference Check

After the completion of the building information models, the process of detecting and registering inconsistencies and physical interferences in the project took place. Some problems were detected earlier, during the modeling process.

In the case study, a matrix for interference check between components was used to support detection of interferences between elements of the several disciplines, as illustrated in Table 2.

Table 2 - Matrix for interference check verification

<table>
<tr><th>Disciplines</th><th colspan="2">Architecture</th><th colspan="2">Structure</th><th colspan="2">HVAC</th><th colspan="2">Plumbing</th></tr>
<tr><td rowspan="5">Architecture</td><td>columns</td><td>walls</td><td rowspan="5" colspan="2"></td><td rowspan="5" colspan="2"></td><td rowspan="5" colspan="2"></td></tr>
<tr><td rowspan="3">beams</td><td>walls</td></tr>
<tr><td>ceilings</td></tr>
<tr><td>windows</td></tr>
<tr><td>windows</td><td>ceilings</td></tr>
<tr><td rowspan="6">Structure</td><td rowspan="2">columns</td><td>columns</td><td rowspan="3">columns</td><td>columns</td><td rowspan="6" colspan="2"></td><td rowspan="6" colspan="2"></td></tr>
<tr><td>beams</td><td>beams</td></tr>
<tr><td rowspan="3">beams</td><td>walls</td><td>slabs</td></tr>
<tr><td>windows</td><td rowspan="2">beams</td><td>beams</td></tr>
<tr><td>ceilings</td><td>slabs</td></tr>
<tr><td>slabs</td><td>slabs</td><td>slabs</td><td>slabs</td></tr>
<tr><td rowspan="5">HVAC</td><td rowspan="5">HVAC ducts & pipes</td><td>ceilings</td><td rowspan="5">HVAC ducts & pipes</td><td rowspan="2">columns</td><td rowspan="5">HVAC pipes</td><td rowspan="5">ventilation ducts</td><td rowspan="5" colspan="2"></td></tr>
<tr><td>beams</td></tr>
<tr><td>slabs</td><td rowspan="2">beams</td></tr>
<tr><td>columns</td></tr>
<tr><td>windows</td><td>slabs</td></tr>
<tr><td rowspan="4">Plumbing</td><td rowspan="4">plumbing</td><td>ceilings</td><td rowspan="4">plumbing</td><td>columns</td><td rowspan="4">plumbing</td><td rowspan="2">HVAC pipes</td><td rowspan="4">plumbing</td><td rowspan="4">plumbing</td></tr>
<tr><td>beams</td><td>beams</td></tr>
<tr><td>slabs</td><td rowspan="2">slabs</td><td rowspan="2">ventilation ducts</td></tr>
<tr><td>columns</td></tr>
</table>

4.3. Results for the Schematic Design Phase (SD)

In the SD phase, 30 problems, including inconsistencies and geometric interferences, were found with the BIM model integrating all the disciplines. At the same phase, the traditional process detected only 20 issues. Among those, 10 were found by both methods, as shown in Figure 6.

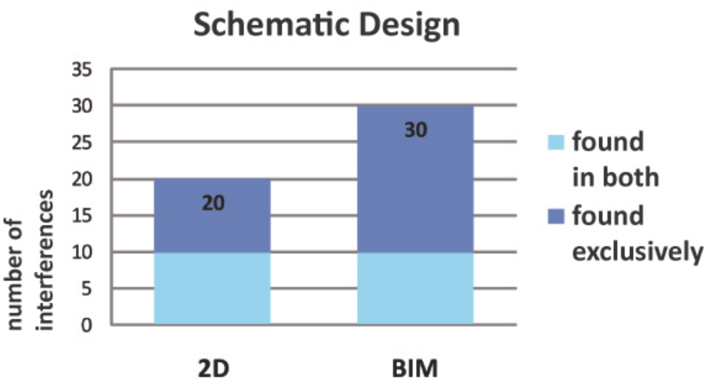

Figure 6 - Number of problems detected by each method of design coordination in the SD phase.

4.4. Results for the Design Development Phase (DD)

In the DD phase, 29 problems were detected by using BIM, including inconsistencies and geometric interferences, while the traditional 2D-process found only 13 inconsistencies. Ten issues were found by both methods (Figure 7).

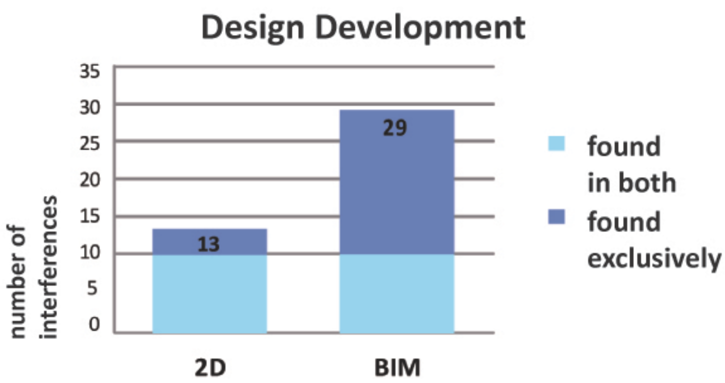

Figure 7 - Number of problems detected by each method of design coordination in the DD phase.

5. ANALYSIS

Although the overall result showed that the methodology using BIM has detected a larger number of inconsistencies, there were some problems found only with the conventional 2D process (10 in the Schematic Design phase, and 3 in the Design Development phase). Among them, there were issues related to component modulation and finishing materials, which could have been detected by the BIM methodology, but were not because this was not the focus of this research and, therefore, they were not modeled in BIM. Other problems, related to design coordination, were not detected by the BIM process because of the first author's lack of experience in design coordination. One such case regarded checking the horizontal alignment of windows in the façade. This demonstrates that professional experience and practice are still important abilities for proper design coordination.

Among the problems only found with the BIM process, many were related to design inconsistency and lack of information and specifications, presenting contradictions to the model development. In the Design Development (DD) phase, some inconsistencies were more easily seen in the BIM model, as they would have demanded the production of many extra 2D drawings in the conventional methodology, especially in such a complex project. Most of these problems were, therefore, detected along the modeling process.

6. CONCLUSIONS

This study aimed to compare the results of the traditional two-dimensional design coordination process and the process using building information models integrating different disciplines. Despite the limited actual practice of the researcher regarding coordination compared to the professionals who developed the case study project, as well as her lack of prior experience with the chosen BIM design tool, it was possible to detect about 75% more interferences in the designs by using BIM than by using the traditional procedure.

Many inconsistencies and geometric interferences found using the 3D modeling had not been found by the conventional process. This can be explained by the limitations of two-dimensional representation for project development.

The building information modeling process not only allows for better visualization of the designs and automatic interference detection, but its own execution allows detection of inconsistencies and lack of design information, as it simulates the construction process to a certain degree. Some significant design problems, however, were found only by the coordinator using the traditional process in 2D, which demonstrates that professional experience supported by the use of a BIM process can bring more benefits not only to the coordination activities, but to the project development as a whole.

It was also identified the potential that BIM tools have to reduce rework and execution time throughout all phases of design, as concluded by Leicht and Messner (2007) in their case study involving Schematic Design (SD). Although the execution time of the models in the study have encompassed the BIM tool learning phase, DD phase took only 25% of the time needed for the SD phase, mainly because the tools enable automatic changes in all views and parametric data editing, instead of pure geometric changes.

The use of BIM tools in the AEC industry is still restricted in Brazilian construction, with barriers related to costs, training, standards and organizational issues. This case study also pointed out the inadequacy of some the tools in the Brazilian market regarding building standards in Brazil.

Even so, if these tools were used to their full potential, they could bring economic benefits to the design and coordination processes, anticipating problems that escape the eyes of experienced design coordinators performing the traditional 2D-based procedure.

ACKNOWLEDGMENTS

The authors would like to thank the firms that collaborated in the case study presented here. The second author acknowledges the support of CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico.

REFERENCES

Cambiaghi, H. (1992) “Projeto e obra no difícil caminho da qualidade”. *Obra, Planejamento & Construção*, n. 37, June 1992. p. 10-12.

Eastman, C. et al. (2008) “BIM Handbook: a Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors”. John Wiley & Sons, New Jersey.

Ferreira, R. C. (2007) “O uso do CAD 3D na compatibilização espacial em projetos de produção de vedações verticais em edificações”. M.Sc. thesis. Departamento de Engenharia de Construção Civil, Escola Politécnica da Universidade de São Paulo. São Paulo. Available at : <http://www.teses.usp.br/teses/disponiveis/3/3146/tde-09012008-144142/publico/Dissertacao_ FINAL.pdf > [accessed May 6, 2011].

FIESP (2008) Federação das Indústrias do Estado de São Paulo. “Proposta de política industrial para a construção civil: edificações”. DECONCIC/FIESP, São Paulo. Available at: <http://www.fiesp.com.br/deconcic/publica%E7%F5es/deconcicpropostaindustrial.pdf> [accessed May 6, 2011].

FIESP (2010) Federação das Indústrias do Estado de São Paulo “9th Brazilian Construction Congress”. DECONCIC/FIESP, São Paulo. Available at:

<http://www.fiesp.com.br/construbusiness/pdf/apresentacoes/ConstBusiness 2010English.pdf>. [accessed May 6, 2011].

General Services Administration (2007) "GSA BIM Guide Series 01: Overview - version 0.60". General Administration Services, Washington. Available at: <http://www.gsa.gov/bim/> [accessed May 6, 2011].

Groover, M. P. (2001) Automation, production systems and computer-integrated manufacturing. 2nd ed., Prentice Hall, Upper Saddle River, NJ.

Korman, T. M. and Tatum, C. B. (2006). "Prototype Tool for Mechanical, Electrical, and Plumbing Coordination". *Journal of Computing in Civil Engineering*, 20 (1) 38-48.

Leicht, R. M.; Messner, J. I. (2007) "Comparing traditional schematic design documentation to a schematic building information model." *In proceedings of CIB W78 24th International Conference on Information Technology in Construction*, June 26-29, Maribor, Slovenia. p.39-46.

Manso, M. A. (2006) "Modelo de sistema de gestão e coordenação de projetos em empresas construtoras e incorporadoras". M.Sc. thesis, Instituto de Pesquisas Tecnológicas do Estado de São Paulo. São Paulo.

Melhado, S. B. (1993) "A qualidade na construção civil e o projeto de edifícios". *In proceedings of the 5th Encontro Nacional de Tecnologia do Ambiente Construído*, São Paulo, Brasil, v.2, p.703-704.

Melhado, S. B. (2005) "Coordenação de projetos de edificações". O Nome da Rosa, São Paulo.

Peralta, A. C. (2002) "Um modelo do processo de projeto de edificações, baseado na engenharia simultânea, em empresas construtoras incorporadoras de pequeno porte". M. Sc. Thesis, Programa de Pós-Graduação em Engenharia de Produção, Universidade Federal de Santa Catarina, Florianópolis, Brazil.

Rodriguez, M. A. A.; and Heineck, L. F. M. (2003) "A construtibilidade no processo de projeto de edificações" *In proceedings of the 3rd Simpósio Brasileiro de Gestão e Economia da Construção, São Carlos.* Available at: <http://www.deciv.ufscar.br/sibragec/trabalhos/artigos/092.pdf>. [accessed May 6, 2011].

Santos, E. T. and Ferreira, R. C. (2008). "Building Design Coordination: Comparing 2D and 3D Methods." *In proceedings of CIB W78 25th International Conference on Information Technology in Construction,* Santiago, Chile, p.166-175.

Scheer, S.; Amorim, S. R. L.; Santos, E. T.; Ferreira, R. C. and Caron, A. M. (2007) "The Scenario and Trends in the Brazilian IT Construction Applications' Experience". *Journal of Information Technology in Construction*, v. 12, p. 193-206.

Shih, N. J. (1996) "A study of 2D and 3D oriented architectural drawing production methods". *Automation in Construction*, 5 (4), p-273-283.

Souza, L. L. A; Amorim, S. L. R. and Lyrio, A. M. (2009) "Impact From the use of BIM in Architectural Design Offices: Real Estate Market Oportunities". *Gestão & Tecnologia de Projetos*, São Carlos,4 (2), p.26-58. Available at: <http://www.arquitetura.eesc.usp.br/posgrad/gestaodeprojetos/jornal2/index.php/gestaodeprojetos/article/view/26/124> [accessed May 6, 2011].

Tse, T. K.; Wong, K. A. and Wong, K. F. (2005) "The utilization of building information models in nD modeling: A study of data interfacing and adoption barriers". ITcon, 10, p.85-110. Available at: <http://www.itcon.org/data/works/att/2005_8.content.05676.pdf> [accessed May 6, 2011].

Staub-French S. and Khanzode A. (2007) "3D and 4D Modeling for design and construction coordination: issues and lessons learned". ITcon Vol. 12, pg. 381-407, Available at: <http://www.itcon.org/2007/26> [accessed Jul 28, 2011].