# Integrated and Collaborative Architectural Design: 10 Years of Experience Teaching BIM

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**Abstract**

In Brazil, undergraduate courses in architecture and urbanism under promote technologically mediated collaboration in design studio classes. The industry is incorporating BIM and has been looking for collaborative skilled employees. Teaching BIM should take into account issues related to student integration through collaborative methods. This paper presents the summary of a study to evaluate the collaborative process mediated by BIM over the past ten years in its capstone course, contemplating learning and educational strategies. Therefore, the following questions ought to be asked: Were design exercises appropriate? Was the adopted dynamics of collaboration coherent? Did the collaborative tools and standards serve the mediating function? Was collaborative training fostered? Action research is the methodology used to conduct this study. Each year, the evaluation process of the previous sequence is carried out, followed by the planning of the current one. Through the historical comparison between the course curriculum and collaboration strategies adopted over the years, there have been changes in the understanding of how to use BIM in a collaborative process for educational purposes. The two-axes collaborative integration method developed over the years of the course, where students are tested to collaborate, at the same time, in a design process and in a research process that assists the design, is an innovation that results from the evaluation cycles based on the research-action method. It was possible to conclude that the essence of teaching collaboration mediated by BIM follows the same precepts of the current BIM definition. To teach BIM, one must comprehend how the processes, policies, and technologies are related to the design teaching goals.

**Keywords**

BIM • Collaborative design • Education • Technology dissemination

## 104.1 Introduction

Brazilian undergraduate courses in architecture and urbanism underpin technologically mediated collaboration in design studio classes. Therefore, they are at odds with the industry, which is incorporating BIM and has been looking for collaborative skilled employees to achieve the benefits of this digitally integrated methodology. In the same manner, the

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intensive use of collaborative processes mediated by BIM favors students' understanding that BIM learning goes beyond technological topics. BIM teaching should take into account issues related to student integration through collaborative methods; otherwise, as Solnosky et al. [1] point out, companies end up hiring technology-savvy graduates and designate them as BIM Managers without them having project management skills. Recent research on teaching methods in technology applied to design indicates there is a change in the way BIM is taught [2]: there is less emphasis on technological issues and a greater focus on stimulating skills in design process and management.

The integration of informatics applied to design aiming at encouraging collaboration has always been one of the leading concerns of the School of Architecture and Urban Design at University of Campinas since its inception, in 1999 [3]. This paper presents the summary of a study that intends to evaluate the collaborative process mediated by BIM over the past ten years in its capstone course, "Design Theory X: Integrated and Collaborative Design Studio," contemplating learning and educational strategies.

## 104.2 Background

### 104.2.1 About the "Design Theory X: Integrated and Collaborative Design Studio" Course

The "Design Theory X: Integrated and Collaborative Design Studio" course is the 10th in the design studios sequence. It offers 4 h per week in the studio and 2 h per week in the computer lab. In the studio, there are design classes and assisting sessions to support design development by groups of students. In the lab, there are classes of fundamentals in integrated and collaborative design and principles of BIM. Whenever necessary, the lab holds workshops on software. Sometimes, the theoretical foundation is also developed through lectures or seminars in the studio. Every year teachers propose a different design exercise and indicate a bibliography related to BIM and design. The Results section in this article present more information about course features, as well as the research results regarding the evolution of the course.

### 104.2.2 Teaching Applied Informatics to Architecture in Brazil in the Years 2000

Unicamp's School of Architecture and Urban Design introduced the Integrated and Collaborative Design Studio in 2007. Its purpose is to provide learning and experience of a digital, integrated and collaborative architectural design practice. It follows the school's principles that guide the use of applied computing since its foundation, as presented by Kowaltoswki et al. [3]. Informatics is not only instrumental but also an integral part of the creative process that influences the solutions.

Despite the disagreements as to how to incorporate digital technology into design studios, it was common sense that education innovation and renovation depend mainly on faculty actions and planning [4, 5]. Vincent and Nardelli [6] pointed out that trying to fit the digital design tools into a traditional studio approach proved to be ineffective, as applied computing favors more immersive design development, which imposes faster training-assessment cycles that students cannot reproduce or fully explain when presenting their work in the studio. Romano and Scarabotto [7] observe that technological evolution necessarily implies a re-evaluation of educational methodologies and re-evaluation of teacher-student relationships. Thus, it seems clear that Brazilian researchers who studied this subject were aware of the challenges, as well as their peers in other parts of the world.

### 104.2.3 Evolution of Teaching BIM and Its Influence in This Course

Over time, there have been many efforts to adopt applied computing to Architecture and Engineering, and consequently BIM, in the curriculum of some Brazilian and other countries universities. Barison [8] described how the teaching of BIM evolved in universities and what the market expected of it between 2000 and 2010. At that time, companies were interested in BIM competencies associated to cost estimation, simulation, interference detection, and quality control, while Civil Engineering and Architecture courses were teaching BIM focused modeling and 3D visualization. Wu and Issa [9] surveyed educators and professionals on BIM education status and career development. They found out that leading approaches to integrating BIM in undergraduate AEC programs aimed at the development of a full BIM class curriculum or included BIM contents in traditional courses; Barison [8] thought as well that priorities on BIM curricula were BIM modeling, analysis, and configuration. However, Solnosky et al. [1] realized that educating future engineers in BIM technology required the integrated project delivery (IPD) collaboration and design approach with industry involvement. An educational strategy consistent with IPD is observed [1] when comparing the pedagogical approach proposed by the School of Architecture faculty for its courses in informatics [3]; therefore, at the moment, we address the following questions for the Integrated and Collaborative Design Studio: Were design exercises appropriate? Was the adopted dynamics of collaboration coherent? Did the collaborative tools and standards serve the mediating function? Was collaborative training fostered?

## 104.3 Research Method

The methodology for this study is action research. Each year, before the beginning of each course, the evaluation process of the previous sequence is carried out, followed by the planning of the current one; during the course implementation, the teachers maintain a monitoring process to make appropriate changes if necessary. Systematic evaluations were applied throughout the years, to understand how students were learning: course portfolio reflections, content analysis, secondary analysis and observational research [5]. The data from the collaborative environment logs were the subject of the secondary analysis. Team-based learning has always been part of the teaching strategy in this course; however, from 2015 on, it is possible to observe that the methodology becomes the axis that structures all the course contents.

## 104.4 Results

### 104.4.1 Results of the Research on the Evolution of the Course

All previous course programs have undergone a documentary analysis, to see if and how planning a new sequence has taken advantage of the experiences and lessons learned from previous ones (Online Resource 01). From these documents, it was possible to gather and catalog information on how teachers conducted the course each year, and which BIM-mediated activities were most encouraged. The tables with the data and formulas analyzed in the results reported here are in Online Resource 02. The totals presented in the ten years course evaluation matrix indicate that the years 2017, 2013, 2012 and 2007, in this order, were those in which integration and collaboration, as well as activities mediated by BIM, occurred more intensively. The settle of an Electronic Document Management System/Common Data Environment (EDMS/CDE) by the teachers is an important policy, as well as the emphasis on interoperability. 4D Planning teaching was more intense in the first six years of the course, and Digital Markup and Cost Analysis activities were fostered more in recent years. Energy Analysis has been fairly well distributed over the years.

From an analysis over the recommended bibliography (Online Resource 03), it was possible to verify an increase in the number of bibliographic indications on BIM when comparing the first five years of the course with the following five years. Figure 104.1 presents overall results.

The publications indicated with more recurrence, that is, more than three times in these ten years, are: The BIM Handbook [10], 9 nominations; AECbytes blog [11], Autodesk BIM Workshop webpage [12], Autodesk Revit 2011 Tutorials webpage [13], and Autodesk Revit Architecture 2012 book [14], with 5 references each; and a Rivka Oxman's journal article [15], 3 nominations.

### 104.4.2 Specific Characteristics of the 2017 Course

A senior professor conducted the 2017 course with the assistance of a Ph.D. student. The proposed challenge was the design of a light rail system with six stations in the city of Santos, which is located on the coast of the state of São Paulo, Brazil. In

| Years | Book | Book Chap. | Implem. Guide | Journal Article | Scientific Event | Soft. Guide | Whitepaper | Magazine | Tutorial | Mag. Article | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-11 | 15 | | | 6 | 2 | | 3 | | | 3 | 29 |
| 12-17 | 7 | 1 | 5 | 4 | | 13 | | 5 | 12 | 5 | 52 |
| Total | 22 | 1 | 5 | 10 | 2 | 13 | 3 | 5 | 12 | 8 | 81 |

**Fig. 104.1** The five-year period comparison of quantities and types of indicated bibliographic references

**Table 104.1** Amount of different software used by students, by category

| Software category | 0 (%) | 1 (%) | 2 (%) | 3 (%) | 4 (%) |
|---|---|---|---|---|---|
| Design | 0 | 0 | 40 | 43 | 17 |
| Desktop publishing | 34 | 66 | 0 | 0 | 0 |
| GIS | 94 | 3 | 3 | 0 | 0 |
| Illustration | 11 | 89 | 0 | 0 | 0 |
| Image processing | 14 | 86 | 0 | 0 | 0 |
| Programming | 91 | 6 | 0 | 3 | 0 |
| Rendering | 69 | 29 | 3 | 0 | 0 |
| Visual programming | 89 | 6 | 6 | 0 | 0 |

the first phase, six teams were in charge of studying visual identity design, technical standards and legislation on rail transport systems, geomorphological and socioeconomic aspects, and mobility issues of the city. Such information formed the foundation used in the second phase. At this stage, the previous groups were rearranged, and the six new ones had to design the stations and surroundings; within each one, pairs or trios of students formed new groups to act according to the disciplines of Architectural Design, Landscape and Urban Design and Interiors and Signage Design. In some moments, as in Exam 03, the students were reunited among disciplines to carry out task proposed by the teachers. The Online Resource 04 provides complete information about the 2017 course program, as well as the different versions developed during the semester.

**BIM action plan diagnosis**. Teachers decided to adopt the BIM Competencies strategy proposed by Succar [16] to develop the BIM action plan. The laboratory's hardware and software were evaluated from the technology point of view (Online Resource 05). The equipment was not able to handle sophisticated 3D modeling, but it was suited for collaboration and communication, practical exercises on interoperability, IFC fundamentals, clash detection, among others. Regarding process and policies, it was decided how the groups would be structured and the theoretical approach to the object of study. Students' skills were taken into consideration. There was a poll with 35 of the 41 enrolled (Table 104.1 and Online Resource 06) with the purpose of learning more about which category of programs they had sufficient knowledge.

83% of the students declared they dominate 2 or 3 different design software: AutoCAD (100%), SketchUp (77%), Revit (60%), Rhino (26%), among others. 12% claimed to know how to use a visual programming tool (Grasshopper or Dynamo) and 9%, programming languages like C, C # or Python. The results of the survey grounded the decision to let students choose to use whatever programs they wanted.

**The BIM action plan**. The goal of the BIM action plan for the course was to facilitate communication and exchange of design information amongst students and between students and teachers, with minimal interference regarding the use of digital tools, but with a very incisive interfering in the process of information and communications management. The course develops design authoring and 3D coordination using BIM.

**Collaborative platform**. Trimble Connect, a solution pointed out by Preidel et al. [17] as a mature approach for a CDE, was adopted as the collaborative platform for communication between teachers and students, as well as to perform 3D coordination, clash detection and create quantity reports from model data. It has a system for synchronizing files on personal computers, facilitating data exchange; allows creation and management of tasks (BCFs), offers a Revit add-on for exporting models, and generates reports in Excel format from data in IFC, SketchUp Pro, and Revit models.

**Design models geolocation**. Geolocation of the team design model files as an essential, non-negotiable premise, was adopted at the beginning of the course, as it deals with the development of several projects in a simultaneous and coordinated fashion in the urban site.

**Use of IFC as the predominant means of information exchange**. Students had classes to learn how to produce quality IFC files from the programs they used, which was vital to perform the integrated visualization of projects in Trimble Connect or in any other software they wanted (Fig. 104.2). A collection of videos and images with samples of student deliveries in Exams 01, 02 and 04 is gathered in Online Resources 07 through 12.


**Fig. 104.2** Geolocalized projects of the teams in the city of Santos

### 104.4.3 Evaluation of Performance Based on Model Data Extraction

The content analysis occurred on automated readings of BIM models delivered by the teams on exam dates. The analyzes encompassed: Clash detection in Exams 01, 02, and 04, and quality audit of the information extracted from the models, in Exam 04. Mapping of the BIM process, related to the flow of design files, delivery dates of exams, and teams, can be checked in Online Resource 13. Table 104.2 and Online Resource 14 show results obtained by clash detection tests on the models delivered in Exams 01, 02, and 04.

It is possible to notice a reduction in the clashes per object rate in almost all the cases, with three exceptions. The increase in team C and F rates is due to the lack of knowledge on how to export a quality IFC file at the time of the first exam. The almost constant value presented by team D is due to the high level of geometric complexity of its design proposal.

*Defining Objects, Parameters, and Values.* Exam 03 was a collaborative work proposed to develop an object classification system (Online Resource 15). Students had to create parameters and fill out related values for six object types chosen in a previous exercise: Doors, Windows, Toilets, Signage Boards, Trees, and Landscape Benches. For objects of type Door, the following parameters applied: Brazilian BIM Standard Code, Cost, Model, Manufacturer, Supplier, Shipping Weight, Noise Reduction Coefficient, Thermal Conductivity Coefficient, Panel Finishes, and Material Type. The other objects

**Table 104.2** Clash checks on the models delivered

| Cl. per obj. | Arch. design | | | Int. and sign. design | | Land. and urb. design | |
|---|---|---|---|---|---|---|---|
| Teams | EX 01 | EX 02 | EX 04 | EX 02 | EX 04 | EX 02 | EX 04 |
| A | 1.25 | 0.00 | – | – | – | 0.45 | – |
| B | 0.32 | 0.30 | 0.21 | – | 0.00 | – | 0.30 |
| C | 0.13 | 0.27 | – | – | – | – | – |
| D | 1.57 | 1.50 | 1.57 | 0.35 | 0.00 | 0.43 | 0.10 |
| E | 0.65 | 0.53 | – | – | – | – | – |
| F | 0.00 | 0.80 | 0.00 | – | 0.00 | – | 0.49 |

**Table 104.3** Results of data audition from the models delivered in exam 04

| Parameters in object types | Corr. (%) | Inc. (%) | Corr. (abs) | Inc. (abs) | Total |
|---|---|---|---|---|---|
| ALL | 72 | 28 | 5659 | 1293 | 6952 |
| Various | 61 | 39 | 1090 | 328 | 1418 |
| DOR and WIN | 67 | 33 | 230 | 120 | 350 |
| LBE and SBO | 60 | 40 | 238 | 44 | 282 |
| TOI | 100 | 0 | 114 | 0 | 114 |
| TRE | 89 | 11 | 1543 | 317 | 1860 |
| SBO | 58 | 42 | 112 | 22 | 134 |
| LBE | 55 | 45 | 346 | 88 | 434 |
| Total | 73 | 27 | 9332 | 2212 | 11544 |

received the same treatment. The evaluation of Exam 04 consisted of verifying whether the elements were in the correct IFC classification; if they had the proper prefix; if there were ten properties previously defined in each object in each model; if values were correctly filled out. Results of the data audition are summarized by parameters' category, in Table 104.3. Other results are in Online Resources 16.

73% of the 11,544 values were correctly filled out by the students. The highest hit rate is in Toilets category, but the chances are that this happened because students used Toilet objects with parameters already filled out. The high accuracy rate in Trees category (89%) confirms that the students learned well how to create and fill out parameters, as no team used tree libraries with pre-filled parameters and values.

**Table 104.4** The average rate of added files: comparison between 2007, 2008, and 2017

| Categories | 2007 | 2008 | 2017 |
|---|---|---|---|
| CAD drawing | 1.13 | 3.15 | 2.68 |
| Document or presentation sheet | 0.74 | 3.85 | 6.34 |
| Image | 5.04 | 10.00 | 12.24 |
| Model—deliverable (IFC) | | | 1.66 |
| Model—design | | | 4.41 |
| Modeling support | | | 0.46 |
| Other | 0.78 | 2.08 | 4.41 |
| Total | 7.70 | 19.08 | 32.22 |

**Table 104.5** Types and quantities of activities in collaborative platforms in 2008 and 2017

| 2008—Autodesk Buzzsaw | | 2017—Trimble connect | |
|---|---|---|---|
| Activity group | Count | Activity group | Count |
| Similar activities | 1049 | Similar activities | 10006 |
| Comment | 0 | Comment | 12 |
| File | 1049 | File | 5678 |
| Folder | 0 | Folder | 4267 |
| Project administration | 0 | Project administration | 49 |
| Other activities | 5 | Other activities | 8596 |
| Markup | 0 | ToDo | 115 |
| Note | 0 | View2D | 12 |
| Publish | 5 | Clash | 368 |
| Link | 0 | Sync | 8101 |
| All activities | 1054 | All activities | 18602 |

### 104.4.4 Comparisons Between the Course of 2017 and Previous Ones

A statistical comparison was performed only among course offerings that registered log uses, that is, through secondary analysis, to verify the evolution of the use of collaborative platforms. Table 104.4 shows the average rate of added files by category. There is a constant increase in the average number of shared files; there is also a reduction in the average number of CAD files created and added to the collaborative platform, per student. Other related results are in Online Resources 17.

Table 104.5 shows the number of activities performed by students in 2008 and 2017, which are grouped and summed by type. Similar operations and other ones (i.e., those that do not exist in the other platform) form a hierarchical top-level grouping for ease of comparison. There is a significant increase in students' adherence to the collaborative platform in all categories. The number of activities divided by the students per year is also a good indicator: there were 81 activities per student in 2008 versus 453.7 in 2017, an increase of 560%. Other findings are in Online Resources 18.

## 104.5 Discussion

In 2017, statistical analysis shows that the efficient sharing of information reduced the rework of the teams. There was an optimization of the workflow through centralized management of information models, and an increased understanding of the value and function of mandates to regulate collaboration and integration. Collaborative platform improved teacher-student communication regarding questions about design, which was answered directly in the BIM models and supported an efficient evaluation of student work. Through the historical comparison between the course curriculum and collaboration strategies adopted in classes over the years, it was possible to perceive changes in the understanding of how to use BIM in a collaborative process with educational purposes.

## 104.6 Conclusion

The results of the analyzes presented in Sect. 104.4 and discussed in Sect. 104.5 are the basis for the answers to the questions raised in Sect. 104.2.3, and support some of the conclusions presented in this section. The evolution of teaching practices contributed to the improvement of teachers as mediators. Technologies also changed from Computer-Aided Architectural Design (CAAD) and EDMS to BIM and CDE. There was an evolution of the process of understanding the course, the methods of collaboration and communication and currently available technologies. The intense exchange between teachers and students and analysis by teachers between cycles resulted in this transformation, which gave the course the character of educational research. Sophisticated design exercises, with the inclusion of environmental requisites, cost analysis, clash detection and other BIM related activities are appropriated for this type of course and require a team effort. The two-axes collaborative integration method developed over the years of the course, where students are tested to collaborate at the same time in a design process and in a research process that assists the design, is an innovation that results from the evaluation cycles based on the research-action method. Such dynamics foster efficient collaboration and can also be promoted involving external teams. The collaborative tools can be better harnessed, and standards development mediates integration understanding. The fostered collaboration training is the knowledge of the efforts and consequences of the conciliatory decision-making process. It is possible to conclude that the essence of collaboration teaching mediated by BIM follows the same precepts of the current BIM definition, taking as reference the academic meaning that is more often attributed to the term [18]. To teach BIM, one must comprehend how the processes, policies, and technologies are related to the design teaching goals.

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