Barriers to Success in a Collaborative Technological Ecosystem: A Study on the Perception of the Interoperability Problem in Civil Engineering Education

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Abstract. In this paper, we report some issues in the learning ecosystem at Zachry Department of Civil Engineering at Texas A&M University related to software interoperability problems that can be considered a limiting factor in the efficiency of the CAD workflow in Civil Engineering education. We describe the structure of an undergraduate course where various CAD packages are used where data must be shared and exchanged among them. We provide a discussion about participant responses and perception toward interoperability, instructor observations, and suggest solutions to common interoperability problems, along with concrete plans to improve the course. The interoperability issues associated with designing in multi-CAD environments may have significant impact on productivity, the level of user-engagement, and the student learning experience.

Keywords: Interoperability · BIM · Curriculum development

1 Introduction

In the Zachry Department of Civil Engineering at Texas A&M University, Building Information Modeling (BIM) software has recently been incorporated as one of the technological tools to support the civil engineering learning ecosystem. Related topics to BIM are first introduced in a compulsory sophomore-level course focusing on Computer-Aided Design (CAD) and visualization skills, with the expectation that

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students will apply these new tools in future courses. The course has undergone continuous modification, with new material initiated based on industry and capstone design class professor feedback. Previously, students have received instruction in a variety of CAD software commonly used in the civil engineering profession (AutoCAD, AutoCAD Civil 3D, and Revit), but each of these programs was used independently of each other, exclusively employing the design aspects for which they were designed. In application, specific projects were assigned considering the capabilities of each program, covering both land development and structural engineering disciplines. Specifically, AutoCAD Civil 3D was previously used for land development projects (rural runway redesign, shopping center construction, and improvements for a city park) and Revit was used to either design a freestanding structure or to provide a structural skeleton for an existing architectural project. The purpose of this course, as well as for the continuous improvements, is to provide for increased competitiveness for student internships and proficiency with industry-standard BIM software so that new graduates can quickly implement their skills.

A new ambit for the class was removing the structural engineering component and instead concentrating on land development projects. This decision was made to better reflect the enrollment numbers between the areas of emphasis offered in the department (General Civil Engineering, Structures, and Transportation). Moreover, another class was developed entirely focusing on BIM and Revit, so these topics were not entirely removed from the curriculum. In order to accomplish this task, two commercial BIM programs (AutoCAD Civil 3D and Autodesk InfraWorks) were used, which generate data and files, which are then shared between them. More specifically, InfraWorks was used to collect and create 3D surface data (terrain and existing roads) in a format that could be exported to AutoCAD Civil 3D for further design modifications. An example is shown in Fig. 1. This process also supplied exact geolocation and aerial imagery to place the surfaces in context (see Figs. 2, 3 and 4). InfraWorks is a cloud-based software, requiring an Autodesk account to access stored design files.

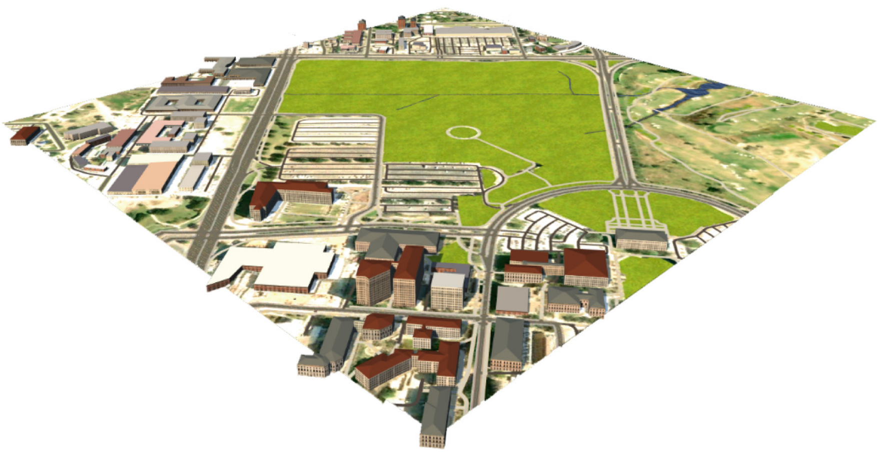

Fig. 1. InfraWorks model of polo field at Texas A&M University

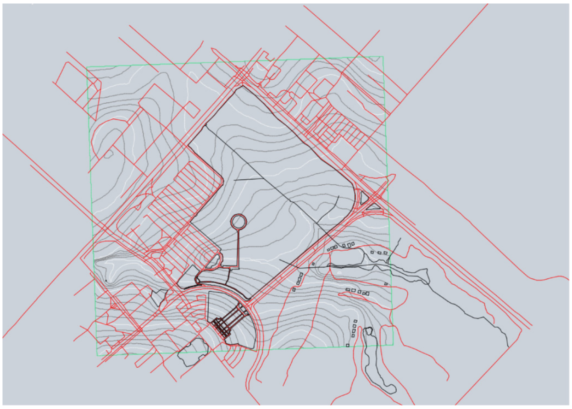

Fig. 2. Civil 3D drawing with imported InfraWorks model.

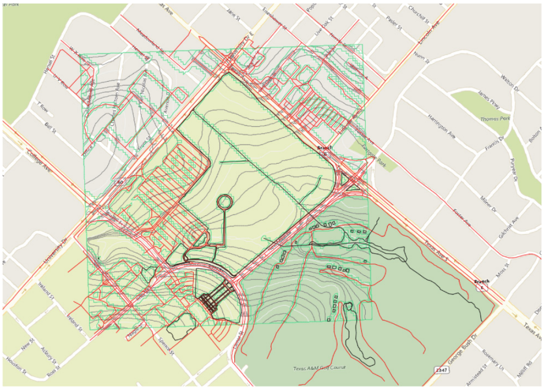

Fig. 3. Civil 3D drawing with imported InfraWorks model with road map and existing transportation surface.

The College of Engineering has instituted a “Bring Your Own Device” program that requires students to purchase a laptop computer that meets stringent specifications. Furthermore, Autodesk provides a useful scholastic community that allows the students to download and access educational versions of professional software. These educational versions have all functionality of the corresponding professional software, but the licenses expire after three years. Certain problems develop because general College of Engineering laptop specifications are not in alignment with specific CAD software system requirements. As an example, college requirements specify 8 GB RAM machines, while AutoCAD Civil 3D can marginally perform on an 8 GB RAM computer (minimum requirements), Autodesk recommends 16 GB RAM.

Ideally, data sharing among these applications and integration within the overall course workflow should be seamless; especially since the same software company developed all CAD packages used in the course. However, various problems were

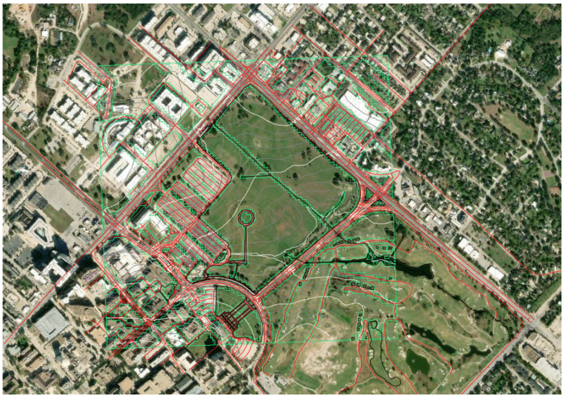

Fig. 4. Civil 3D drawing with imported InfraWorks model with aerial map and existing transportation surface.

observed and reported which can have a negative impact on the dynamics of the course as well as on the overall student learning experience. In this paper, we discuss the students' view on CAD interoperability in the context of this course and explore the effects on a collaborative CAD environment and civil engineering education.

2 Interoperability

Many definitions of interoperability have been proposed in the technical and academic literature. For example, IEEE defines interoperability as "the ability of two or more systems or elements to exchange information and to use the information that has been exchanged" [1]. According to authors Levine et al. [2], interoperability can be understood as "the degree to which a set of communicating systems are (i) able to exchange specified state data, and (ii) operate on that state data according to specified, agreed to, operational semantics." Carney et al. [3] introduced the ideas of purpose (or goal) and context (or environment), and added them to the definition provided by Levine et al. [2]: "the ability of a collection of communicating entities to (i) share specified information and (ii) operate on that information according to a shared operational semantics (iii) in order to achieve a specified purpose in a given context." Compatibility was described by Panetto as a prerequisite for interoperability [4]. Regarding technological ecosystems, researchers García-Holgado and García-Peñalvo [5] stated that "the information flow between two software components implies there is an integration between those components."

For the purposes of this paper, interoperability is defined as the ability of a system to provide services to and accept services from other systems, which involves communication, with the purpose of operating together in a more effective manner [4, 6]. Researchers generally agree on the barriers that hinder interoperability [6–8]. Although barriers may exist at technical, operational, and organizational levels, this paper focuses exclusively on technical barriers, specifically software interoperability and how users in the context of civil engineering education perceive these barriers.

The problem of interoperability has a long history in the field of CAD and Computer-Aided Engineering (CAE). In the Architecture, Engineering, and Construction (AEC) industries, problems continue to exist concerning a lack of interoperability of software in reference to exchanging design information in electronic format [9]. Historically, interoperability problems have resulted in geometric errors, inconsistencies, broken geometry, and loss of design intent. These problems may result in longer product development cycles due to rework, inefficient reuse of designs, translation costs, and wasted opportunities for innovation, which often translate to significant losses for the company, both in terms of time and money [10].

Over time, CAD systems have evolved considerably to include more than just the geometric representation of a product. Today's CAD systems are capable of conveying material information, design intent, annotations, product structure and manufacturing process data, to name a few, within the 3D model. Furthermore, many modern CAD packages also include collaborative tools across the enterprise and/or cloud-based services. Although some efforts have been made to facilitate information exchange (such as the development of neutral translation formats and the implementation of modules and pre-processing interfaces for these formats), the increase in complexity along with the understandable reluctance of vendors to share their intellectual property, have naturally contributed to this problem.

From a technical standpoint, basic interoperability aspects and data exchange issues in CAD were originally discussed by Gerbino and colleagues [11]. These aspects include the accuracy of the mathematical descriptions of the model in the different CAD systems, the types of geometry representations, and the different internal description and interpretation of the model by the kernel of each CAD system. Interoperability problems can also originate from poor modeling practices. Substandard geometry often results in poor data exchange. As a result, software vendors have not yet been able to fully solve the problem of interoperability and users are still far from working on a completely interoperable multi-CAD environment.

Realizing interoperability as being an important problem, several Architecture, Engineering and Construction groups have taken steps toward the development of standards to facilitate data exchange between software platforms [12]. Examples include the Open Geospatial Consortium [13] and ifcXML model and implementation support groups [14]. In the context of civil engineering CAD education, the integration of CAD product data among the various systems is a fundamental aspect to ensure efficiency of the learning process and facilitate course dynamics. By focusing on design and modeling tasks rather than data translation and migration issues, students will be able to collaborate more effectively, shorten the time to complete assignments, reduce frustration, and improve the overall quality of the deliverables. This paper primarily examines CAD interoperability from a student's perspective, the goal of which is to understand how interoperability is perceived in the overall CAD workflow, and identify problems that may hinder student learning. In the next section, we discuss the results of a user study conducted as part of a civil engineering course.

3 User Study

In the context of the course previously described in the introductory section of this paper, a commonly reported and important student problem involved creation of large surface files on the computer lab workstations, which were split into several temporary files (or may have existed as one file) stored on the local machine, which was/were externally referenced in the surface files exported to AutoCAD Civil 3D and were therefore inaccessible on student laptops. Recognizing this and other problems concerned with the interoperability between these CAD programs, a user study was conducted to investigate user perception and the extent to which interoperability can be considered a limiting factor in the efficiency of the CAD workflow in civil engineering education.

A survey was constructed to investigate problems encountered with software interoperability and completed by fifty-one students. The survey utilized a 5-point Likert Scale (questionnaire designating gradations of approval) [15]: 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; and 5 = Strongly Agree.

The results of this survey reveal that eighty-six percent of the respondents downloaded the free education software from Autodesk, with ninety-one percent of those students using this software to complete assignments, in addition to using university-provided workstations. As the College of Engineering requires all students to purchase a computer that meets required specifications, student unwillingness to access the free software is not related to lack of computer ownership. The survey asked the respondents to respond the following seven statements:

1. Using each individual software package and managing files within that package was easy and straightforward (Ex. External References and Blocks).
2. From a user interaction standpoint, sharing files between programs was easy, intuitive, and straightforward (Ex. Civil 3D and InfraWorks).
3. Sharing files between programs is a reliable and seamless process.
4. I trust the accuracy of my imported files.
5. In terms of interface design and overall user interaction, it was easy for me to work and switch from one software package to another.
6. When sharing files between applications, it was easy for me to keep track of all my files and the overall workflow.
7. It was easy to share files and work on different computers (e.g. lab workstation, personal laptop, etc.).

Students were also afforded an opportunity to provide detailed responses to the following questions:

1. What problems did you encounter using an individual software package?
2. What problems did you encounter when sharing files between programs?
3. What problems did you encounter when sharing files between computers (e.g. personal device vs. lab workstation)?

4 Results and Discussion

The student responses are shown in Table 1.

Table 1. Student response to interoperability questionnaire.

Question	Student response	Std. dev.
Using each individual software package and managing files within that package was easy and straightforward (e.g. external references and blocks)	3.94	0.68
From a user interaction standpoint, sharing files between programs was easy, intuitive and straightforward (e.g. Revit, Civil 3D and InfraWorks)	3.90	0.76
Sharing files between programs is a reliable and seamless process	3.65	0.93
I trust the accuracy of my imported files	4.00	0.89
In terms of interface design and overall user interaction, it was easy for me to work and switch from one software package to another	3.69	0.95
When sharing files between applications, it was easy for me to keep track of all my files and the overall workflow	3.94	0.76
It was easy to share files and work on different computers (e.g. lab workstation, personal laptop, etc.)	3.27	1.15

For Question 1, the students agreed with the statement, “Using each individual software package and managing files was easy and straightforward,” responding with a value of 3.94. The respondents almost replied with an identical score (3.90) to the second question, “From a user interaction standpoint, sharing files between programs was easy, intuitive, and straightforward.” In regard to the third question, students largely agreed (3.65) with the statement, “Sharing files between programs is a reliable and seamless process.” For the fourth question, students agreed (4.00) with the statement, “I trust the accuracy of my files.” For the fifth question, student respondents mostly agreed (3.69) with the statement, “In terms of interface design and overall user interaction, it was easy for me to work and switch from one software package to another.” For the sixth question, students agreed (3.94) with the statement, “When sharing files between applications, it was easy for me to keep track of all my files and the overall workflow.” For the final question, students were generally neutral (3.27) in their response to the question, “It was easy to share files and work on different computers.”

When examining the standard deviation of the responses, all values were moderately large, considering the 5-point possible scale. They ranged from a low value of 0.68 (for Question 1) to a high value of 1.15 (for Question 7). That these values were so wide-ranging leads one to surmise that there is a definite vagueness to the responses, with the highest standard deviation value corresponding to the question with the least amount of agreement. Anecdotally, it appears that most students were unsure of their replies, but the general pattern appears to be in agreement with all queried statements.

The responses to the open-ended questions were examined and placed in comparable sub-categories in order to compile the information in a useable format. All fifty-one students answered these questions, providing additional, unprompted specific feedback facilitating course improvement.

The first question queried problems encountered using an individual software package. Ten students reported that their own personal device was slower than the departmental-provided computer, which is an unexpected response, since the lab computers are relatively dated, leading one to question if the students purchased a machine that satisfied college required specifications. Ten students reported issues with corrupted files and frequent program crashes. Other reported problems included issues with a smaller screen with their own laptops and the inability of InfraWorks to create a model (encountered by the instructor also). Moreover, and mentioned in one student comment, is that some students opted not to purchase an external wireless mouse, even though the cost is minimal. CAD design using the track pad is considerably more arduous.

The second open-ended question ascertained student problems sharing files between AutoCAD Civil 3D and InfraWorks. The students overwhelmingly responded (thirty-five responses) that no problems were encountered when sharing files between these programs. The student response to this question is not in alignment with their answer to Question 2 using the Likert Scale (3.94), however. This lack of congruence could be reinforced by the wide-ranging standard deviation values reported for the seven questions.

The third open-ended question addressed sharing files between computers. Twelve students reported experiencing no problems sharing files, but six students admitted that they only used one device for all assignments (either laptop-only or lab computer-only). The other response of particular interest was that temporary files were either missing or difficult to locate when using different machines. These responses seem to mimic what was illustrated in Question 7 using the Likert Scale (3.27). For this case, the InfraWorks models are by default located in the "Documents" folder, and it is not readily apparent (or possible?) to browse for another location when creating them.

5 Instructor Observations

The instructor also encountered various file sharing issues when deploying the class during the semester, as he primarily used his office computer for lecture development and the instructor machine in the classroom. Since all curriculum preparation was accomplished on his office workstation, he failed to foresee these file sharing issues.

Student refusal to download the free educational CAD software was based on either absence of scholastic engagement, lack of hard drive space, or reluctance to install *Boot Camp Assistant* on their personal device. In addressing the latter issue, a technology help desk, funded by the college, is staffed to assist students with this task. Some students may have chosen not to run the programs on Mac OS because of a reluctance to decrease available hard drive space or a perceived reduced battery life in labs without adequate electric outlets, but this issue was not queried on the questionnaire. Since utilizing one machine for all design steps helps to reduce interoperability issues (at least between devices), future versions of this course will require students to download the free educational software, even if their personal laptop only meets minimum specifications. Proof of successful software installation will also be required.

The issue of whether the college required device specifications are adequate is a thornier issue. The requirements are college-wide, with many majors not requiring the high-end computer speed or graphic cards of computers performing CAD design. To further complicate the issue, students are not enrolled in a major until their sophomore year, before the specifications of the computer they need is known. It is unrealistic to expect the college to upgrade their computer specifications for the small number of departments that need a more robust machine. So, in the end, there may not exist a practical solution.

6 Conclusions

This paper examined the issue of CAD interoperability from a student perspective in the context of Civil Engineering education. Our results shed light on the impact of interoperability on course dynamics and the overall learning experience. The problem becomes more relevant as more institutions embrace “Bring Your Own Device” type of policies.

While interoperability issues continue to cause complications with using CAD software in the classroom, the advantages dwarf these problems. As the software continues to become more complex, useful, and powerful, it is vital that the newest technologies are discussed and utilized in an educational setting so that the next generation of engineers has state-of-the-art tools in which to be successful.

The proposed solutions, (1) requiring one computer to be used for all design work (either student device or lab workstation), (2) encouraging students to purchase (or upgrade to) a CAD-ready machine, and (3) compelling students with Mac OS systems to have their hard drive partitioned and having *Boot Camp Assistant* installed, are only quick fixes, so that the learning process is not disrupted. Hopefully the technological irregularities will be ironed out in future versions of the software as their adoption becomes more commonplace.

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