Tools and methods for paperless student design projects

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Abstract

Despite the advances in information technology, many activities in the design process are still predominantly paper-based. Adopting paperless processes will prepare our students for new ways of working, will streamline many existing processes associated with student design projects, and will facilitate dissemination and archiving of project documentation. This paper discusses methods and tools to support shared computer workspaces, digital design notebooks, digital review and markup of documents and CAD models, and digital design documentation including CAD models and video. We evaluate available software tools including Microsoft SharePoint, Microsoft OneNote and Adobe Acrobat 9 Pro Extended.

1 Introduction

Despite the advances in information technology, many activities in the design process are still predominantly paper-based. Design documentation is a mix of paper and digital files, with frequent conversions: files are printed, and paper is scanned.

During conceptual design, students record freehand sketches, handwritten notes, and engineering calculations in a design notebook. These are incomplete records of the design as much of the design record exists in parallel as computer files. Paper notebooks are difficult to share, and are difficult to evaluate or include in the final design documentation. Students frequently scan pages of their notebook to include in their final report.

The potential of “electronic notebooks” has been recognized since the early days of personal computing [1][2][3]. While technology has improved tremendously since these early prototype systems, electronic notebooks are still not widely used. Tablet

PCs have tremendous potential to support digital notebooks, but their adoption in design education has been sporadic. In some trials, it emerged that students are unsure how to use Tablet PCs effectively in the design process [4]. Without appropriate software, training and processes, students tend to use Tablet PCs as regular laptops.

CAD and CAE tools have largely replaced paper drawings for detailed design. Design documentation at this stage is often in the form of CAD models. Sharing of CAD data remains difficult due to the complex links between multiple files, and the need for CAD software to open and view the models. As a result, students typically reduce the models to either engineering drawings, or screen shots, which are then included in printed reports. They may also print screenshots and physically paste them into paper notebooks.

Design projects are usually evaluated on the basis of printed progress reports and a final report, which are submitted for grading and feedback. Instructors typically mark comments by hand directly on the printed report, and return it to the students for revision.

At the end of the design project, a final report is typically printed and submitted to the library for archiving. Supporting files like CAD models, spreadsheets, analysis results, etc. are usually not included.

This paper discusses some of the requirements and tools to support a paperless design process in an academic setting.

2 Paperless processes and tools

No single software tool currently exists to support a digital design process from start to finish. As a result, paperless processes must be built on top of separate complementary and usually overlapping software tools.

The following sections describe some of the tools and methods that can be used to support paperless design.

2.1 Shared computer workspace

A paperless design process requires a shared computer workspace for the management and integration of multiple information types. These include documents, presentations, spreadsheets, engineering drawings, CAD models, freehand sketches, rough calculations, vendor data sheets, videos, animations, photos, etc. It should be possible to link, search, restructure, sort, categorize and annotate various information objects. It should be possible to combine different objects in a single view, e.g. sketches, text and calculations.

Microsoft SharePoint is a web-based shared workspace and shared document management system. It also provides a range of standard project management tools including calendars, schedules, task lists, contact lists, discussion boards, and polls. Documents are managed in shared document libraries. They can be opened and edited using Office applications. The document libraries provide version management, and file locking to prevent overwriting of changes.

We have used SharePoint to support team projects in many courses since 2002 [5], and we will continue to explore how to best use it. We have been unable to find any published case studies or research papers discussing the use of SharePoint in engineering design education, so there are no established best practices to follow.

While it is a relatively mature product, SharePoint still has some important weaknesses. In particular, it is not usable as a Product Data Management (PDM) system, as it cannot manage product structure associated with CAD data. A separate product like SolidWorks PDMWorks is required for CAD data management [6].

2.2 Digital shared design notebooks.

Usually, student design teams maintain individual records in personal design notebooks or journals, and team information in paper-based Product Development Files. In a paperless environment, all information would be created and shared in digital form. Tools are required to allow freehand sketching and engineering calculations of the type normally done with pencil and paper.

Most existing computer tools are poorly adapted to this application. One tool with much of the required functionality is Microsoft OneNote, particularly combined with a TabletPC or other pen-based

interface. Most students have laptops, and Microsoft OneNote is bundled with the student edition of Office.

OneNote is based on a notebook metaphor. Each notebook consists of pages grouped into sections. Text, freehand drawings and handwritten notes can be placed anywhere on a page. Other objects including screen captures, images, web pages, file attachments, and audio/video recordings can also be included.

OneNote includes powerful facilities for sharing notebooks between members of a team. A shared notebook must be located in shared network folder, or a SharePoint document library. Users can work on a shared notebook offline, and synchronize it by connecting to the server. Our tests suggest that this capability is still immature. We were able to share notebooks using SharePoint, but synchronizing them could take many minutes. In other words, there was a long delay between one user making a change to a notebook page, and having the change appear on the shared notebook page on another computer.

OneNote also provides live sharing to allow multiple team members to share a notebook on multiple computers in real time. Preliminary testing shows that this works efficiently, with changes appearing in everyone's notebook almost instantly. However, we encountered problems in establishing connections between computers in most of our tests. This functionality also appears to be unreliable, and further testing is required.

OneNote satisfies many of the requirements for an electronic notebook, and in fact has all of the functionality of a paper notebook. However, it lacks effective integration with Office applications, or with CAD. For instance, there is no apparent way to incorporate a freehand sketch in OneNote into a Word document. There is also no way to import sketch geometry into a CAD sketching environment for further refinement.

OneNote notebooks can be saved as Word documents, but drawing objects are not properly displayed. The resulting document is completely unstructured, and extensive formatting is required to prepare a report. Due to lack of integration, it is difficult to prepare a rough draft in OneNote, and refine it in Word.

OneNote notebooks can be exported as PDF documents, with all formatting and layout preserved. This is a useful capability, as it allows the inclusion of a design notebook as part of the final design documentation.

2.3 Digital design review and evaluation process.

The typical review process consists of submitting hardcopy to a faculty advisor, who marks it up with a red pencil and returns the marked-up copy to the students. With appropriate tools, design documentation would be submitted, marked up and returned digitally.

note { Microsoft Word and Adobe Acrobat both provide comprehensive tools for document commenting and annotation. Tools include: highlighting, written comments, inserting text, and deleting text. Acrobat also provides drawing tools, and freehand annotation using a pen. Word provides similar freehand annotation for Tablet PC users only, in the form of Ink Tools.

Users with the full version of Acrobat can add comments to any PDF document. To allow commenting in Acrobat Reader, commenting must be explicitly enabled when creating the PDF file. Interestingly, this is rarely enabled. We were unable to find a single example of a PDF file that allowed commenting using Acrobat Reader. Luckily, we discovered that any PDF file can be opened in Acrobat, and resaved with commenting enabled. This paper is saved as a PDF with commenting enabled.

We have used both WebCT [7] and SharePoint to implement a basic report submission-markup-return workflow. In WebCT, students upload their report as either a Word or PDF file. The instructor downloads the file, opens it in either Word or Acrobat, adds comments and annotations, and uploads the commented file to WebCT for students to review. The process is similar in SharePoint. If the document is edited in place (using Word), the download/upload steps can be eliminated. The commented version can either be saved as a new version of the same file, or as a separate file with a different name.

An important advantage of a digital review process is that comments and feedback are available to all members of the team, as well as the instructor. It is very useful to go back to comments made on progress reports, to see if they have been addressed. With paper-based evaluation, instructors must rely on memory as they have returned the marked-up report to the students.

2.4 Digital Literature Reviews

Information gathering is a key phase of the design process. Web-based research databases are a standard tool today, and many research papers are available as downloadable PDFs. Most students and researchers then print the files, and add comments and highlighting

by hand. These printed and marked up copies are difficult to store, search or share.

With Acrobat, it is possible to highlight and annotate the PDFs directly, and share the result with others in digital form. It is also possible to save the PDF with commenting enabled, so that others can use Acrobat Reader to add comments.

A SharePoint document library can be used to share PDF research articles. Commenting is cumulative, so each reviewer's comments are added to the previous comments. All comments are time stamped, and are identified by the reviewer's name.

2.5 Digital review of CAD models

CAD models are usually discussed by opening the model in the CAD software and gathering around a computer, or printing screenshots to be marked up by hand.

A variety of lightweight CAD formats and associated viewers have appeared in recent years. These tools allow CAD models to be shared, viewed and annotated without needing the full CAD software.

Important initiatives and standards include the JT format promoted Siemens [8], the 3D XML format promoted by Dassault [9], and the eDrawing format promoted by SolidWorks [10]. JT and 3D XML are competing standards, and are not universally supported by all CAD vendors. eDrawings is bundled with SolidWorks, and provides good functionality, but it doesn't support other CAD formats without additional license fees.

Adobe Acrobat 9 Pro Extended [11] provides comparable functionality, and works with virtually any CAD data format. Acrobat allows the embedding of fully interactive CAD models into PDF documents. The resulting model can be rotated, zoomed, and examined interactively. Furthermore, Acrobat allows comments and annotations to be added directly to the geometry. No special viewer is required, as this is all supported by the free Acrobat Reader.

This is a very useful capability for both design documentation, and design reviews. Students can embed CAD models in PDF files, which can be annotated or archived.

2.6 Embedding CAD models into documents

Adobe Acrobat 9 Pro Extended can also embed 3D content into Microsoft Office documents. An example of an embedded model is shown in Figure 1. If this is

document is printed, the figure appears as an image. If this document is opened in Acrobat Reader, this figure becomes a fully interactive 3D model. If commenting is enabled, it is also possible to add annotations to the model.

Figure 1. Embedded CAD model of an oil pump, generated from a SolidWorks sample assembly model. This 3D model is fully interactive when viewed as a PDF in Acrobat Reader.

We have found that embedding of 3D content into Word is poorly documented and unreliable. Word macros must be enabled to interact with the 3D content. Macros are often disabled by default.

This limitation is acceptable if we consider the Word document to be a draft, which will be saved as a PDF for distribution. The 3D content is enabled in the PDF regardless of the macro settings in Word.

2.6.1 Embedded Video

Acrobat 9 Pro Extended also allows the embedding of video into PDF and Office documents. Videos in any format are converted to Flash Video Format (*.flv). This format can be played by Acrobat Reader. If the document is printed, the video appears as an image. A SolidWorks animation of the oil pump shown in Figure 1 was created and saved as an AVI video file. Acrobat converts all video formats into Flash Video format when the document is saved as a PDF.

Figure 2. Embedded video of SolidWorks oil pump animation.

Embedded videos are not included in Word documents, but are linked to video files in another location. Acrobat converts the video file into Flash Video format, and puts the resulting file in a subfolder. We obtained an error message when attempting to use a SharePoint document library. This is poorly documented, and limits the portability of the document. For example, if a Word file with embedded video is uploaded to a SharePoint server, the link to the video file is lost.

If we wish to use Word as our main document authoring tool, and manage files using SharePoint, then these issues must be clearly understood, and detailed workarounds must be included in instructions to students.

2.7 Digital dissemination and archiving of design documentation.

Traditional student design documentation has been paper-based, consisting of a formal printed report and set of drawings. In recent years, these printed documents have been supplemented with additional digital files, perhaps on a CD or DVD.

The documentation for a design project can involve dozens of files of all kinds, including reports, presentations, spreadsheets, CAD models, images, videos, and other files. Managing, disseminating and archiving design documentation consisting of both paper reports and a collection of digital files is problematic. For the past several years, we have required students to submit a CD or DVD containing all project files. This is still unsatisfactory, as the disks must be stored and are difficult to share.

Adobe Acrobat can create PDF Portfolios, which are collections of digital files embedded in a single PDF file. PDF Portfolios are similar to ZIP files. They can

be opened and browsed using Acrobat Reader, and all of the files can be opened using their native applications. PDF Portfolios are an ideal way to disseminate and archive complete project documentation in digital form, particularly since PDF is recognized as a universal standard for digital documents.

We used Acrobat to create a PDF portfolio containing all the files submitted by a capstone design team. These files were submitted on a DVD, helpfully organized into folders. The folder structure was preserved in the PDF Portfolio. The portfolio contained over 160 files in multiple folders, and resulted in a 300 MB PDF file. Document types included Word documents, PowerPoint presentations, Excel spreadsheets, SolidWorks CAD models, working drawings in SolidWorks and PDF format, and animations. The portfolio included two animation files in AVI format, with a combined size of over 270MB.

We are working with Western Libraries to evaluate the use of PDF Portfolios as a mechanism for archiving design documentation in an institutional digital repository. These repositories are essentially databases of PDF documents, with associated metadata for cataloging and searching. The potentially large size of PDF Portfolios may be an issue.

3 Technical issues and problems

During our evaluation, we encountered many glitches and problems using these tools. Online searching quickly revealed that these are common occurrences, and that solutions are difficult to find.

Many of the features described in this paper are not well documented, and they appear to be not widely known. When glitches are encountered, it is difficult to find help online.

Widespread adoption of workflows based on these tools in an educational setting has an element of risk, since technical problems are very likely. A limited trial is recommended before more widespread implementation. Significant IT support is likely to be required to troubleshoot technical problems.

4 Case Study

Many of the ideas described in this paper have not yet been tested with student design teams. However, we have evaluated the tools carefully, and have used many of them in the preparation of this paper. Collaboration

between the co-authors was done using SharePoint, supplemented by email and occasional meetings. The draft paper was created using Word. The Word file was shared in a SharePoint document library. It was edited in place, from several different computers. We enabled versioning, so that each time the document was edited and saved, a new version was created.

SharePoint locks a file when it is open for editing, preventing overwriting of changes by other users. The lock is released when the document is closed. On several occasions, the file remained locked even after the document was saved and closed from Word. On other occasions, the file became locked during an editing session, and could not be saved. In those instances, we were forced to save the file with a different name. The cause of this problem is unknown.

We wished to use this paper to demonstrate some of the capabilities of Acrobat, rather than just describing them. To that end, we embedded a 3D SolidWorks model, and a SolidWorks animation as an embedded video. We discovered that video content is not embedded in the Word file, but is linked to an external video file. This is poorly documented, and can lead to problems if it is not understood. SharePoint cannot maintain links to external files, so it was necessary to add the video file at the very end, just before saving the paper as a PDF document.

We found that it is impossible to demonstrate all of the functionality by embedding content in Word and just saving as PDF. We required a two-stage process. The first stage consisted of the usual preparation of the paper in Word. The final step was embedding the video content, and then creating a PDF document. Using Acrobat, we added some comments and annotations, and added a sample annotated CAD model as a separate PDF. These steps must be done sequentially. If the Word file is edited, a new PDF must be created, and the steps repeated.

Acrobat provides limited facilities for editing, organizing and formatting a PDF document. In particular, it can combine multiple PDF documents into a single document.

Finally, we have found that there is no easy way to incorporate the unstructured content from a OneNote notebook into a structured Word document. However, a notebook can be saved as a PDF, which can be incorporated into an existing PDF document.

The PDF version of this paper contains PDF appendices containing an annotated 3D model of the

oil pump described in figs 1 and 2, and a sample notebook page from OneNote.

5 Barriers to adoption

Collaboration is a socio-technical process, involving both human and technical factors. Technical collaboration tools are bound to fail without an understanding of human behavior and culture. Simply providing tools does not ensure that collaboration will occur. The issues surrounding design collaboration have been comprehensively reviewed by Lu et al. [12].

Students have little or no training in collaborative methods, and effective practices are not necessarily learned simply by working in a team. Instead of collaborating, students often divide up tasks, and work independently. Students tend to consider work in progress to be “private”, and there is reluctance to share it before it is in a polished form.

Students are naturally concerned about their individual marks, and fairness of evaluation. If individual contributions are not identified, there is a risk freeloading by some team members. Students may adopt strategies to maximize their own mark, at the expense of collaboration. Withholding information is one possible strategy.

People are resistant to change. People prefer to use familiar methods that work well enough, rather than adopting new methods that might work better. In many cases, they are unaware of available collaboration tools.

Finally, the technology is often poorly designed, unreliable, inflexible, and difficult to use. People wishing to use technology to support collaboration often become frustrated if it seems more trouble than it is worth.

6 Conclusions

This paper reviews some of the paper-based processes in student design projects, and proposes tools and methods to replace these with digital processes. The proposed tools are widely available, but their use in supporting student projects is still uncommon. The best and most effective way to use these tools must be established through hands-on testing and evaluation. Once workable processes are developed, they should be documented with clear guidelines and instructions. These tools should then be tested on a pilot basis by

student design teams to further refine the process and identify problems and workarounds.

7 References

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With a Tablet PC, OneNote can be used exactly like a paper notebook

$$\delta = \frac{Fl^3}{3EI}$$

It can do a lot more, like annotating screenshots:

The keyboard can also be used to enter text. Sometimes this is faster than handwriting.