Lost in Translation

Technological Views on Preserving CAD

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15 August 2014

Abstract

This presentation forms part of a panel *Frameworks for the Discussion of Architectural Digital Data*. It reflects on the many technological challenges of preserving CAD models, and offers some possible ways forward.

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1 Introduction

Before I begin. . . I am a digital curation specialist with an interest in engineering data, and in particular computer-aided design. Even though this session is concerned with architectural models, it is important to remember CAD is used in many areas, from archaeology to video games. Each group of users has its own priorities, and that affects both the CAD systems aimed at them and the properties that need to be preserved.

And following from that, if you only take one thing from my talk it should be this: The main technological barrier to preserving CAD is variety

- of 3D geometric representations
- of *non-geometric information supporting* advanced modelling techniques
- of uses *to which CAD models can be put*

2 3D geometric representations

How do you draw in 3D? In approximate chronological order:

¶ **Wire-frame** A line drawing but in 3D (see Figure 1). The shape is picked out by its edges. But you just have a frame: there are no real surfaces involved, so you can't define what goes on away from the edges. Plus ¶ things quickly start to look crowded on the screen once the design gets more complex. To solve these problems one needs to introduce the concept of a surface.

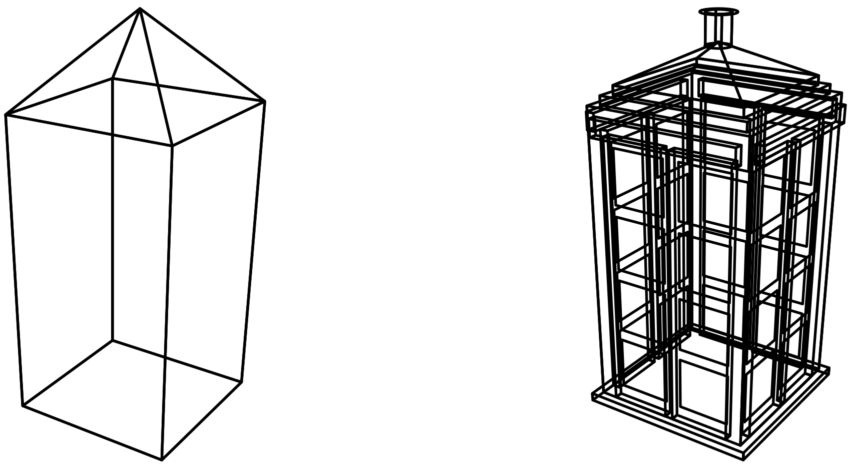

Figure 1: Wire-frame modelling. Note how the version on the right is much harder to 'read' than the one on the left.

¶ **Surface modelling** Various ways of doing this; the slide (Figure 2) shows some of the more common ones. You can completely represent the geometry but you

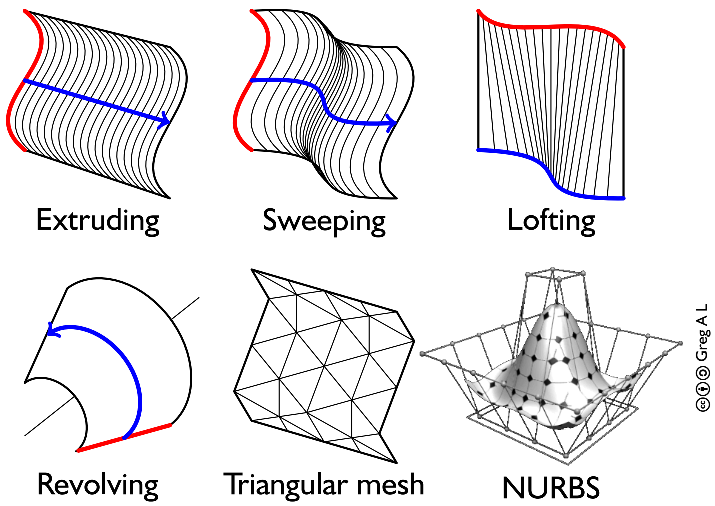

Figure 2: Surface modelling

can't analyse it: it's not easy to ensure all these surfaces join up to form solid objects, nor to calculate where the centre of mass is going to be. To do that you need to introduce the concept of solidity. And there are two quite different ways of doing that: CSG and B-Rep.

¶ **Constructive Solid Geometry** Building up a solid object by deforming simple shapes and adding, subtracting, and intersecting them (see Figure 3). The CGI for the 1982 film *Tron* was all done in SynthaVision, the first commercial solid modeller, which used CSG.

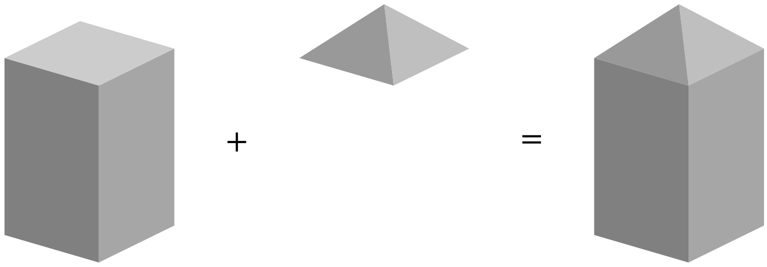

Figure 3: Constructive Solid Geometry

¶ **Boundary representation** Building up a solid object by fusing together a set of surfaces (see Figure 4). This is somewhat more powerful, but you may be wondering how you get all the edges to line up…the computer does something clever. But the clever thing it does, varies between systems.

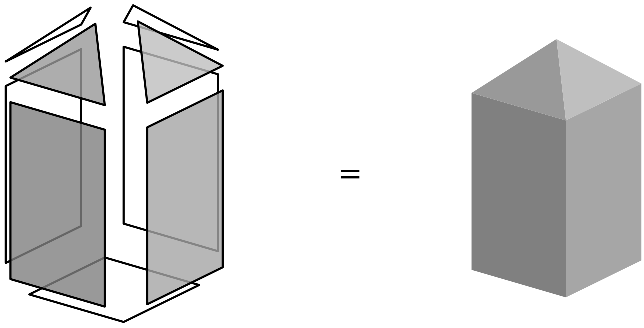

Figure 4: Boundary representation

Constructing a CAD model is not like producing a bitmap image where the end product can be defined simply and easily. It's more like creating a web page, where you write a set of instructions for the computer to follow. The bit of a CAD system that turns the instructions into geometry is called a modelling kernel. ¶ And just as web sites can

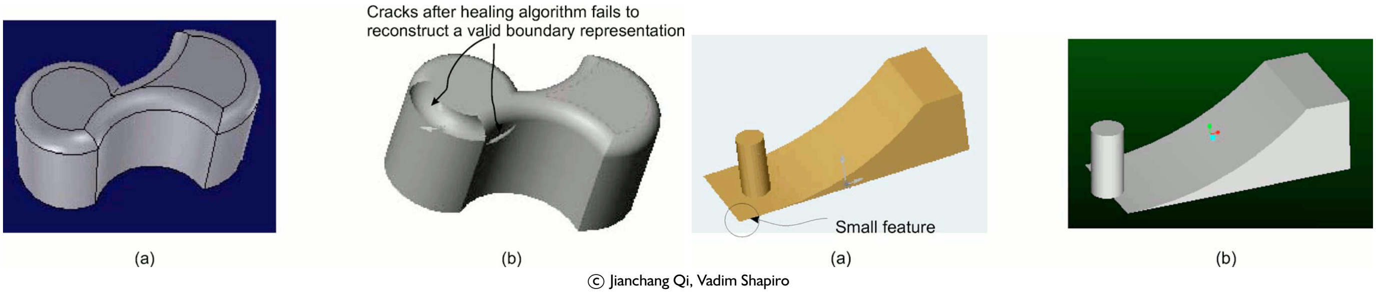

Figure 5: Mistranslation and misinterpretation of CAD data

look and behave differently in different browsers, you can end up with quite different geometry by running the same instructions through two different kernels (see Figure 5).

And in fact because of the complexity of the maths involved the discrepancies tend to be somewhat greater.

¶ In summary, then:

- There are many incompatible ways of *turning 3D geometry into 3D models, and conversely*
- There are many incompatible ways of interpreting 3D models *as 3D geometry*.

3 Advanced modelling techniques

The geometry is just the start. The CAD marketplace is intensely competitive, and vendors are constantly innovating to solve more and more of their customers' problems...systems become obsolete alarmingly quickly.

¶ Construction history modelling (see Figure 6) is a bit like the ultimate undo button. Not only does it allow the designer to step back through previous editing sessions, it also allows the designer to introduce a change in one of the earlier stages of the design and then replay subsequent editing actions.

1. Insert cylinder $l = 20$ $r = 1.0$

   ⟵ Change cylinder $l = 40$ $r = 0.5$

2. Insert sprocket $r = 3.0$
3. Fit sprocket to cylinder
4. Group cylinder and sprocket
5. Scale group by $1.75\times$

...

Figure 6: Construction history modelling

¶ Procedural modelling (see Figure 7), meanwhile, is like Word or Excel macros writ large...apply algorithms not only to automate repetitive tasks but to give surfaces fine texture, generate realistic snowdrifts or extrapolate whole cityscapes from a single building...used extensively in virtual worlds...used in architecture for creating intricate patterns.

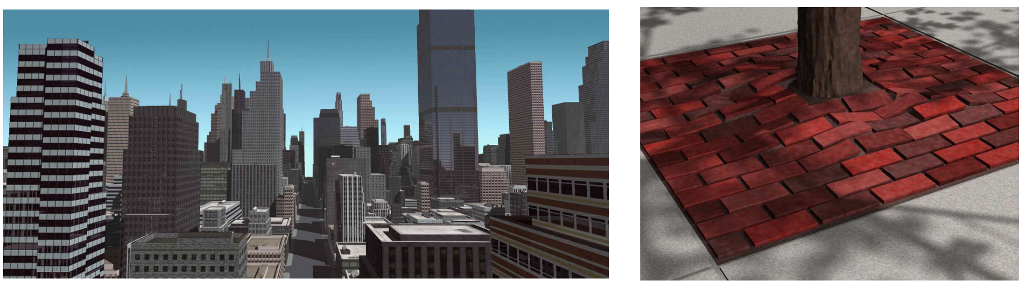

Figure 7: Procedural modelling was used to generate the city (left) and to texture and displace the bricks (right)

¶ Parametric modelling helps to make design easier to adjust (see Figure 8). Aspects of the design are made to depend on variables, and constraints are added so the computer knows how to adjust things should those variables change. This means you can rapidly try out many small variations in order to find optimal solutions.

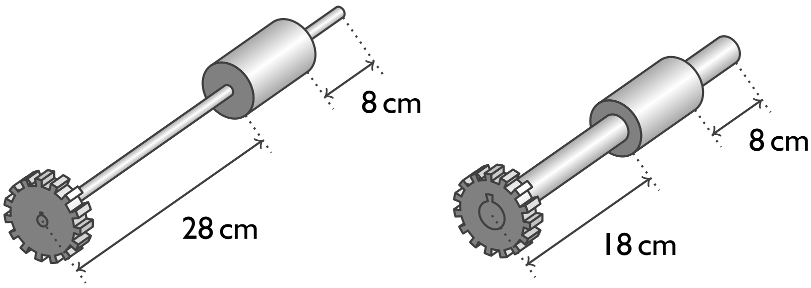

Figure 8: Parametric modelling was used here to adjust the design and position of a gear wheel and pulley to accommodate a shorter, thicker drive shaft

¶ Feature-based modelling is about making explicit the engineering significance of certain shapes in the design. So a curved blend between two surfaces might be there as an artefact of the manufacturing process or as a deliberate design decision to spread the stress; the feature semantics would tell you which. Incidentally, this sort of thing can cause conflicts. Take this shape (Figure 9).

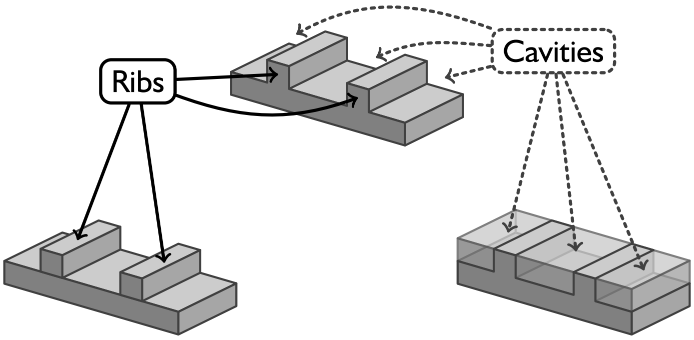

Figure 9: Sample model with an ambiguous feature set

The designer might need this marked up as rib features applied to a base surface in order to calculate the optimum distribution of ribs. The manufacturing engineer, though, might need it marked up as cavities cut out of a thick surface. It's not usually possible to have both in the same model.

¶ The point with all of these techniques is that they embed masses of additional information into the model. That information would almost certainly be required if someone needed to modify the design *(examples?)*, and it might also be useful for anyone trying to understand the model: why it ended up like it did, where a particular quirk was introduced. In summary, then:

- CAD models contain much more than just geometry.
- The geometry might be useless without the extra information.

4 Use cases

Lastly…CAD models are not just used by CAD systems. There are a whole host of systems that use them. Take this example.

¶ CAD systems commonly let you include the same part many times in an assembly (see Figure 10), so if you change it in one place it changes everywhere. Even handier, they may have a library of standard parts…preloaded with feature semantics, parametric properties…Architectural CAD package might have doors, windows, staircases…

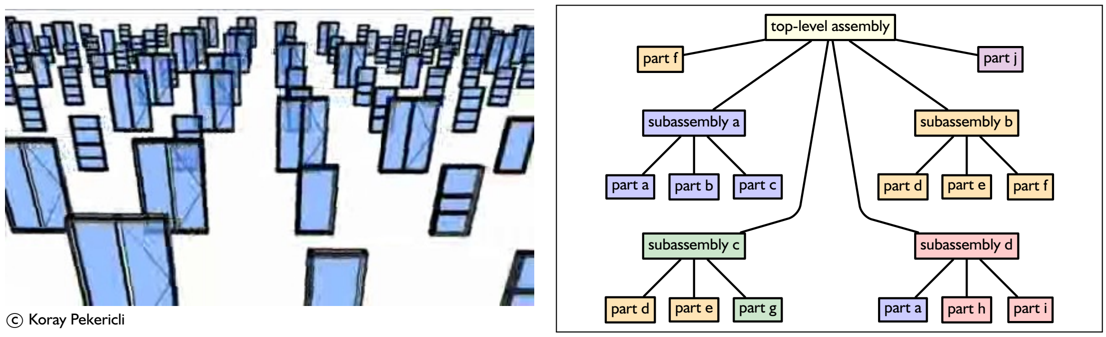

Figure 10: Reusing standard parts

If these parts are hard-coded into the software, it can be very difficult to represent them reliably in a different system. The other alternative is having the parts in separate CAD files and included in an assembly by reference. But that means having to keep track of many different files and ensuring they point to each other correctly when placed on a different file system…relative path names, IDs managed by a central register…In industrial engineering, this would be done by the Product Lifecycle Management (PLM) system…in architecture and construction, a Building Information Model (BIM) system.

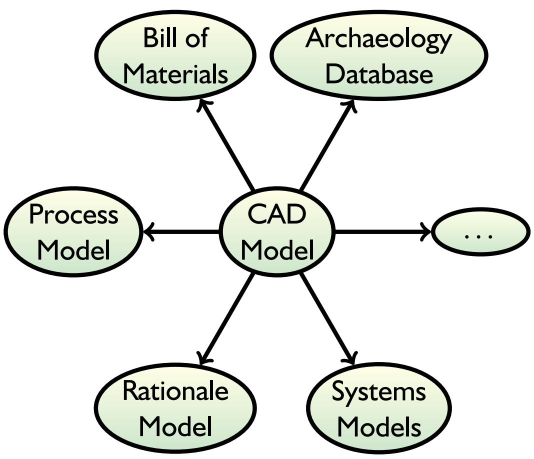

Figure 11: CAD models are just part of the story

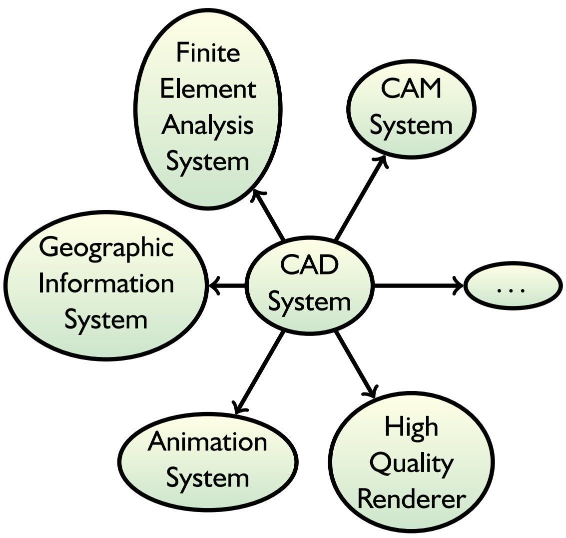

Figure 12: CAD models are used by more than just CAD systems

¶ Such systems do more than just assemble CAD files (see Figure 11)…manage relationships with external databases, wiring diagrams and so on, any of which might be needed for full understanding and reusability of the CAD model. Relationships might be static or dynamic…*(BoM example)*. PLM and BIM systems also manage the security of the information... preservation systems might need to mimic the access controls of these systems, or circumvent security features built into CAD models themselves.

¶ CAD models are also read by FEA tools, manufacturing systems, geographic information systems and CGI renderers and ray tracers (see Figure 12). So if you are looking to preserve CAD models, you might need to think about whether these other systems will be able to read them.

- You might need to coordinate CAD models with many other types of information.
- You might need to *take into account functionality beyond that provided by CAD systems*.

5 Possible solutions

That's enough doom and gloom, what about solutions? People have been working on exchange standards since the late 1970s.

¶ The first one of note was IGES (see Figure 13).[1] By the time they finished with it, it was highly expressive, but it had no conformance standards, so CAD vendors could pick and choose which parts they supported. § So there was never any guarantee that a particular exchange would work. Even so, most systems support some of it.

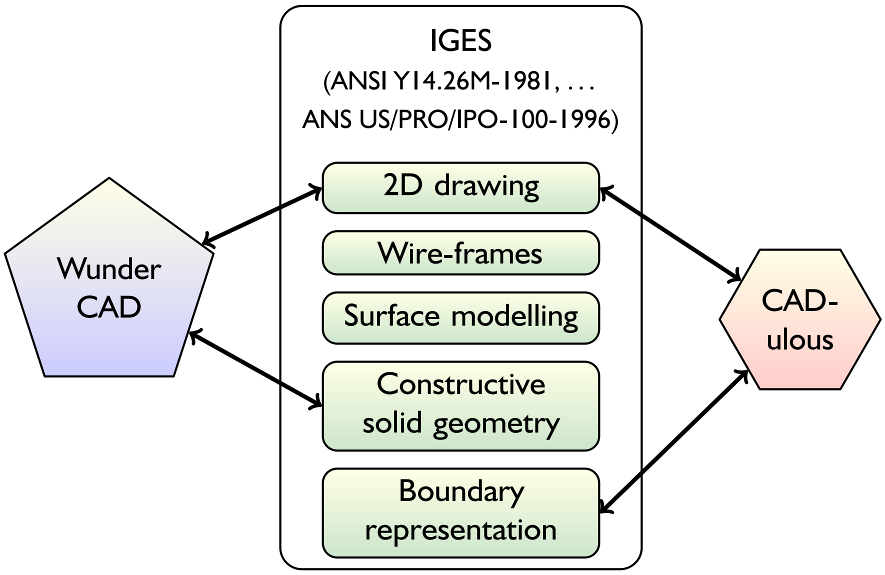

Figure 13: The IGES standard tried to please everyone, but was self-defeating (NB. the CAD systems are fictional!)

¶ There were other attempts, notably in France and Germany,[2] before ISO stepped in with the standard to end all standards: STEP. STEP (ISO 10303) covers all aspects of product model data, and is correspondingly huge. At 590 parts it is the biggest ISO standard by some margin. To make it easier to deal with, STEP itself has application protocols which are tailored to particular circumstances. § A companion standard,

[1] IGES was first published in 1981, but was withdrawn in 2006.

[2] SET (*Standard D'Echange et de Transfert*) and VDA-FS (*Verband der Automobilindustrie-Flächen-Schnittstelle*) respectively.

LOTAR (NAS 9300/EN 9300), is under development explaining how to use it for long term archiving. And there is also the CAx Implementer's Forum where CAD vendors can test the compliance of their converters. But this is aimed more at industrial engineering applications, what about architecture?

¶ The Industry Foundation Classes developed by buildingSMART International were recently published as a full standard (ISO 16739:2013), and there are also companion standards such as the National BIM Standard – United States (NBIMS-US) and the AEC (UK) BIM Protocol.[3] But I think it is fair to say these are still in their early stages, so it's a matter of doing the best we can with the limited options available.[4]

¶ A couple of years ago I was asked to come up with some recommendations for preserving CAD models, and after scouring the literature these are the ones I came up with.

- *CAD files can be used for many different purposes, so it is important for an archive to* Establish why a CAD model will be kept, then target the required properties for preservation.
- Create tests that can prove whether these properties have survived.
- Keep native CAD models for as long as they can be read.
- Normalise to STEP/IFC and a geometry-only standard (or two).
- Don't forget supporting documentation, especially local conventions and 'house style'.
- Campaign for better support for standard formats in CAD systems! *Having to comply with regulations is a strong motivator for vendors to do the right thing.*

The full report is available from the Digital Preservation Coalition website (see the link below).

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The DCC is supported by Jisc.

For more information, please visit http://www.dcc.ac.uk/

'Preserving CAD' report: http://dx.doi.org/10.7207/twr13-02

[3] The British Standards Institute also recently published PAS 1192-2 Information management for the capital/delivery phase of construction projects, standardising BIM for government contracts. Specifically relating to CAD, standard 'house styles' have been defined, e.g. the United States National CAD Standard, the AEC (UK) CAD Standards For Layer Naming.

[4] Another standard gaining traction in architecture is ASTM E2807 Standard Specification for 3D Imaging Data Exchange, Version 1.0 ('E57'), which targets point cloud data, especially laser scan data.