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THE CHALLENGES OF ASSESSING DIGITAL PRODUCT DESIGN

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ABSTRACT
To capitalise on digital product design's capability of producing any shape, designers will need to think in new ways, with more imagination, increased creativity and 'direct' customer input. New design tools and methods will have to be developed for data capture and design inputs. It will be necessary to have CAD systems that can interpret design intent and are completely user friendly for customer-led design. Ultimately, our role will be to develop a hybrid designer that would be skilled in aesthetics, design and technology as well as rapid manufacturing techniques. Today, at Bournemouth University we are developing innovative techniques to efficiently and accurately assess digital product design. The aim is to develop the designers of the future.
This paper presents the techniques that overcome the challenges of assessing digital design from concept to prototype. Some of these methods are derived from industrial practices. The paper covers digital concepts both in two-dimensional and three-dimensional form as well as models generated from point clouds (i.e. scanned data). The challenges of assessing CAD models are investigated and solutions presented. The importance of design quality in engineering simulation is highlighted. Methods of assessment are suggested that are applicable for simulations including structural, thermal, dynamics, fluid and combined analysis such as multiphysics.

Keywords: reverse engineering, CAD, FEA, additive technology

1 INTRODUCTION

Competition, increasing complexity of designs and reduced product life cycles have driven industries to develop products more rapidly and more economically through the use of digital means. Consequently, new technologies and systems have been developed to assist the designer and the engineer during the development process. It is therefore necessary for academic institutions to provide product design students with the necessary knowledge and skills required for the design of modern products in a rapidly changing global design industry.

Bournemouth University have developed courses which provide in-depth knowledge and understanding of modern product design and development methods in the strategic management of the design process. These courses also cover the use of modern technologies such as computer aided design (CAD), computer aided engineering, design and manufacturing simulation (*e.g.* FEA), reverse engineering (RE), rapid prototyping (RP) and rapid manufacturing (RM). Figure 1 represents the different routes that modern product design students can choose to achieve a physical or virtual working prototype at the University.

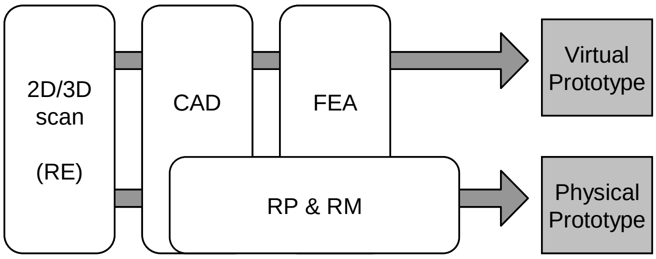

Figure 1 Modern product design routes

An efficient learning and teaching strategy must include some assessments of the digital design. This presents some challenges. The following sections discuss the challenges encountered in relatively new areas of digital product design such as 3D scanning and surface editing, freeform modelling and finite element modelling and optimisation.

2 REVERSE ENGINEERING

Reverse engineering (RE), in this context, is the creation of virtual components or surfaces from physical objects. This procedure is not new, but historically the manipulation of the huge amounts of point cloud data created has always been the Achilles' heal. Recently improved computer power and software has taken this subject out of the research domain and into industry, initially in inspection departments. Bournemouth University has been using its' 3D scanning equipment for research on many varied and specialised projects, ranging from 40,000 year old footprints [1], to the scanning of complex rotors and custom hip prosthesis. The specialist software used on these projects runs into tens of thousands of pounds, but critically the very recent inclusion of point cloud functionality in mid-range CAD packages, such as SolidWorks has made it more widely available to industry. Importantly since this inclusion, RE is available in all our CAD studios (over 60 seats) and not just a single seat as previously. This inclusion will allow greater hands on experience for students in the form of tutorials and the inclusion in projects and the integration into the design process [2]. Introducing RE processes and technologies into the curriculum pose some interesting problems for assessment and the following sections will highlight these and some possible solutions.

2.1 Data capture

Point cloud data obtained by laser can require a significant amount of set-up prior to scan. Reference points may need to be added to objects being scanned or even some surface preparation. The strategy of scanning and methodology of preparation prior to the scan are important criteria for assessment. Poor preparation or incorrect methodology can easily lead to poor results. Figure 2 displays an example of poor quality scanning, in which holes and artefacts in the scan data are clearly visible.

Other point cloud data, such as that obtained from medical imaging sources like MRI or CT scans will yield results that do not need 'line of sight' and therefore internal geometry can also be captured. Whilst the data from these sources is often more complete, there are many areas for assessment here also: from scan slice intervals to region separation. Region separation relies on the grouping of areas of grey in the original images to produce separate volumes of specific materials e.g. cortical and cancellous in bone. Emphasis should be on good methodology rather than specific results during assessment of the critical data capture stage.

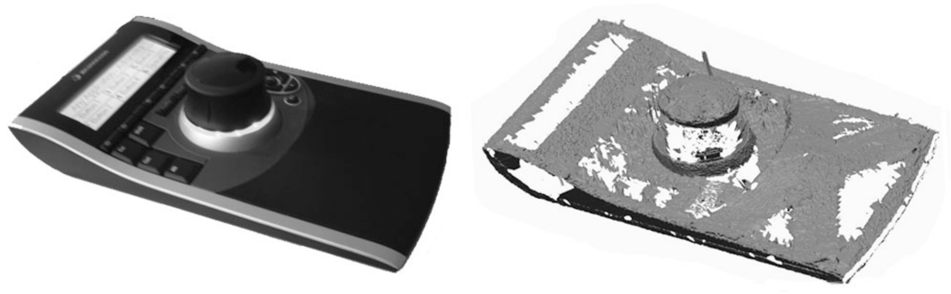

Figure 2 Insufficient preparations prior to scanning can lead to poor results (right)

2.2 Data Cleaning, Smoothing and Surface Output

Point cloud data from laser scan can be ‘corrupted’ by many variables, including: noise, reflections, holes and ghosting. The raw point cloud data produced by the scanner thus needs to be processed before subsequent modeling operations can be performed [3]. Processing such as cleaning, smoothing and stitching can have a huge impact on model accuracy, and so it is imperative that the student includes copies of the original data for comparison. Similarly, the creation of surfaces from the ‘cleaned’ scanned data often adds another level of processing where accuracy can be lost. Comparison of raw data, cleaned and smoothed meshes, and final surfaces is highly recommended during assessment. This comparison can be either visual, using CAD surfacing tools (example shown in Figure 3), or with more sophisticated deviation analysis tools that can report the amount the created surface or mesh deviates from the scanned original.

3 COMPUTER AIDED DESIGN

CAD for the personal user is being enhanced annually by advances in personal computers, particularly in the area of memory, graphics, storage and processing power. These advances have lead to students having the ability to use modelling tools previously available to only large design organisations and manufacturers.

These advances are continually driving new assessment requirements for students at all levels; from basic sketching, to advanced surface modelling using NURBS modelling techniques. Through parametric modelling students have the ability to create many iterations easily and quickly.

3.1 2D Geometry

CAD modelling assessment must start at basic 2D sketching, but with new freeform modelling techniques this area can be omitted. Sketches (2D line drawings) must be constrained using both geometric and dimensional constraints to achieve a robust model. History trees must be ordered and features named to ensure features can be easily identified and suppressed during assessment.

Curve Analysis in sketch form can be analysed through curve comb tools to ensure the power of a created curve flows smoothly through single or adjoined curves whilst the inclusion of positional (G0), tangential (G1), curvature (G2), and acceleration (G3) constraints provide constraints that achieve class A surfaces [4]. These tools have become available to students in the last few years and have greatly increased modelling capabilities which traditionally limited them to standard geometry constraints. CAD systems that incorporate these advanced features may be too expensive for the small companies to purchase, but these features are rapidly filtering down to more affordable mid-range CAD packages.

3.2 3D Geometry

Surface modelling has provided students with the ability to produce models that not only provide the function for which they are required, but are also aesthetically pleasing; this can be seen in all aspects of current design from high street products to Formula 1 motor racing and aerospace design.

Assessment of work at this level requires not only the tools to analyse sketches in the form of curve combs, but tools to analyse the created surfaces themselves. Such tools are included in the CAD programs themselves, and must be used by students to analyse and improve their own models and by the assessor to evaluate.

Radius analysis of surfaces can be undertaken and a Gaussian scale used to show curvature change in the surface. This shows either a smooth radius change along and between surfaces, or highlight areas of large change, such as creases.

Zebra stripes help to visually evaluate the quality of a surface. Curvature continuous surfaces show as smooth flowing stripes, whilst broken tangency displays as an abrupt change in the direction of the stripes. Using zebra stripes can provide a fast visual check of a full model (see Figure 3).

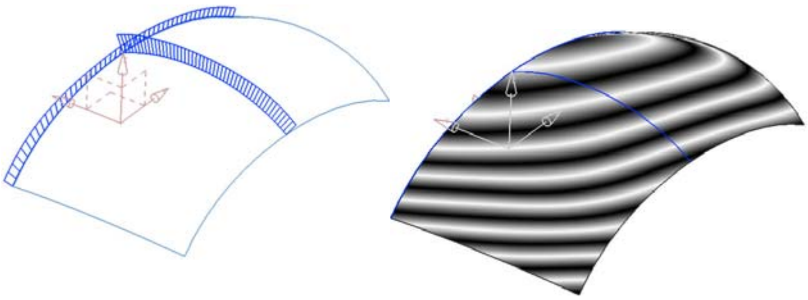

Figure 3 Curve combs (left) used on 2D paths and zebra stripes (right) on the 3D surface

3.3 Rendering

Improvements in CAD functionality have been partnered by improvements in high quality image rendering through the CAD programs themselves, and stand alone rendering packages. There are five basic elements to assess when creating a high quality render of a model: materials and textures, lighting, visual effects, environments, shading and image features.

These advances in modelling have provided a giant leap in what students can produce and need to learn to stay at the forefront of design compared to previous years. The internet has provided dedicated sites and forums for both industry and students to share modelling and rendering techniques as well as to showcase their own models. This can be a great benefit for self learning to both industry and students alike, but can also lead to Plagiarism.

4 FINITE ELEMENT ANALYSIS

The assessment of finite element analysis (FEA) is not new. Velay (1994) presented some innovative solutions during the 1990s. However, FEA software has developed considerably since then and advanced analyses are now undertaken by product design students. Over the years, academic staff at Bournemouth University have become aware of the need for appropriate assessments for FEA. This is now assessed via the design of a part within an assembly by using FEA as an optimization tool. The assessment strategy is discussed below.

4.1 Set up of the problem

The aim of the assignment is to enable the students to demonstrate an advanced understanding of a design optimisation process using FEA. The students are given an assembly in digital form with a missing part. The missing part is critical to the assembly in terms of structural integrity. In order to motivate students it is recommended that an assembly is selected from a real product or the assessment is linked to an existing enterprise activity. The students are then required to design and model a new part using given criteria. For this, they use their engineering judgement together with FEA. This methodology greatly reduces the risk of plagiarism and enhances student creativity. The key areas for assessment include the meshing strategy, the accuracy of the boundary conditions, the choice of material and the critical understanding of the optimisation process.

4.2 Meshing strategy and quality

The meshing strategy comprises four important areas. The choice of element type is critical. The student must defend their decision for using one of the following types of element: beam, shell, solid, plane stress, plane strain or axisymmetric. The mesh refinement and its location are also very important for generating an efficient mesh of high quality. Students are encouraged to investigate the convergence of outputs such as stresses and displacements together with the number of elements. This allows the designer to evaluate the degree of accuracy of the analysis and therefore calculate an appropriate safety factor. Finally, marks can be allocated for studies which use more advanced elements or techniques such as mass, spring and contact elements or symmetry and anti-symmetry.

4.3 Boundary conditions

Boundary conditions greatly influence the output of finite element analyses. The values of forces, pressures, heat flux, temperatures, etc must be supported by appropriate means. The restraints on the finite element model must reflect as well as possible the real life scenario. The use of contact elements greatly enhances the accuracy of the boundary conditions. However, this also adds penalties in terms of complexity and time of analysis. The different combinations of boundary conditions must be investigated in order to set up an efficient and accurate optimization process.

4.4 Material properties

More and more FEA software now incorporates a database of material. This greatly reduces the risk of inputting wrong values for the key parameters such as the density, Young's modulus, Poisson's ratio and yield strength. The authors noted that students who entered their own variables for the material properties were more fluent and creative in terms of materials choice. It is important for product designers to be able to select (or implement) any materials, especially at the detailed design stage of a product's development.

4.5 Critical understanding of the results

Students are encouraged to present four or five iterations of their design. Iterations are derived from the FEA results of the previous ones together with some engineering judgments. At each iteration, key outputs (e.g. equivalent stress, displacement, temperature, natural frequency) are monitored and recorded. The conclusions draw on the variations of these key monitors together with the optimum design. This allows the students to gain a better understanding of design optimisation.

5 CONCLUSION

The range of affordable 3D scanners is increasing rapidly, and with mid-range CAD software now including point cloud functionality the use of RE is now expanding, both in academia and industry. The almost limitless applications for RE mean that it can be introduced to the curriculum at many levels. Simple comparisons and inbuilt tools form the basis for assessment. The now common functionality of importing hand drawn sketches into CAD has created something of a renaissance for student sketching. Using these sketches as guides for the CAD modelling is helping stimulate student creativity and assist in achieving a pure design intent. Asessment of CAD must take into account the basics of sketching, geometric constraints, and design planning with a stable history tree, whilst the assessment of complex surfaces can be achieved using embedded tools. The use of FEA for designing and optimising structural parts as an iterative process encourages students to learn about design optimisation, develops their understanding of FEA as a design tool and ultimately enhances their creativity.

REFERENCES

[1] Gonzalez,S., Huddart, D., Bennett, M. R. & Gonzalez-Huesca, A. (2006) Human footprints in Central Mexico older than 40,000 years. *Quaternary Science Reviews*, 25, 201-222.

[2] Eves, B., Hogarth, P., Mathias, M., Velay, X. & Hewitt, J. In Bohemia, E., Hilton, K., McMahon, C. and Clarke, A. eds. *Shaping the Future?*, pp. 475-480 (Institution of Enginering Designer and The Design Society, 2007).

[3] Gross, M., Heinzle, S., Keiser, R., Pauly, M., Scandella, S., Weyrich, T. In Alexa, M., Rusinkiewicz, S. eds. *Eurographics Symposium on Point Based Graphics.* (2004)

[4] Percoco, G., 2005, A Comparison between Surface Reconstruction Methodologies. *In:* CPI 2005, 4th International Conference Integrated design and production, 9th-10th November 2005, Casablana.

[5] Velay, X. Teaching finite element analysis and modelling. In Hogarth, P. eds. *PDE94 Product Design Education*, (Institution of Engineering Designer and Bournemouth Uiniversity Society, 1994).

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