Digital Design - the potential of Computer Aided Designing in design learning environments

RESEARCH

Abstract

Many, if not most, schools in England and Wales now include the use of 3-dimensional CAD modelling skills in their design and technology curriculum. The impact of the CAD in Schools programme has been significant, at least in terms of the large numbers of trained teachers and the improved quality of student output in the form of visual images and product realisation. There remains, however, the question of its impact on the quality of design, not just in terms of 'design output' but also in terms of 'design development' and 'design quality'. This keynote presentation is concerned with the need to develop a student's ability to *design* and the use of computer-based tools to effectively enhance that development. In this context it considers the potential of CAD activities as a part of design and technology work; the development of appropriate CAD modelling capability and implications for the nature of design and technology curricula.

Key words

CAD, modelling, curriculum, pedagogy, design

Introduction

This aims of this keynote address are to place the activity of Computer Aided Design (CAD) into the context of learning about, or through, designing. To do this, a number of topics concerned with CAD activities are discussed and their relationship with designing and making activities are illustrated. Whilst the focus is on 3D CAD modelling and product design in order to provide this illustration, the elements of CAD and design that are explored may be transferred across a much wider range of applications. These include:

- an outline of the currently perceived potential of CAD;
- more advanced implementation of CAD activities;
- design modelling in CAD;
- capturing design developments through CAD.

Consideration of these topics leads to the consideration of the nature of design and technology itself.

The potential of CAD in design and technology education

This is really a reminder of the potential of CAD as perceived by teachers of design and technology and reflected in the DfES/DATA CAD in Schools programme (www.cadinschools.org). The most significant use of CAD, currently, is to provide design *output* in the form of rendered images, engineering (working) drawings and manufacturing (prototyping). Assuming that a design concept or idea can be suitably modelled in the CAD system, any of these outputs will help students to better visualise and make what they design.

It is now possible to provide photorealistic images of detailed designs as they appear within a CAD system. They provide a means of illustrating how a design will appear, and can be particularly effective if placed in a design context. This might be by simply providing a background that represents the product's environment, or it may be that the product is shown being operated by a person or in conjunction with other products or parts. The images in Figure 1 illustrate the high quality of rendered image that is available from a CAD system. The tripod has been linked to a separate camera image, to illustrate its purpose, scale and context of use, whilst the respirator unit includes more complex, fabric, surfaces on some parts of the product. This helps to communicate the design intention, and can be extended by animating the design to illustrate elements of its operation or function. Such images are beguiling. They suggest a level of completion and accuracy that may, or may not, be correctly attributed to the detailed design development of the student project.

Figure 1: Photorealistic CAD renderings of a universal camera tripod and respirator unit

Engineering or detailed drawings (sometimes referred to as 'working' drawings) have long been a requirement of examinations boards, and others, to support the workshop activities associated with prototypes, mock-ups and manufacturing (Mcmahon and Browne, 1998). There is little doubt that by automatically providing the traditional elevations, views and detailed drawings much time and effort can be saved, and students can move more effectively to workshop-based activities. These drawings can be relied upon to represent accurate dimensions or to provide accurate templates that may be used to help cut and shape the parts of a project prototype. Once again, the drawing output is taken from the CAD model of a design, and is able to represent significant design detail, where it exists.

Manufactured or prototyped parts can be made by Computer Numerical Control (CNC) equipment and, increasingly, by Rapid Prototyping (RP) equipment. Such equipment provides a direct link between the 3D CAD model and the part to be made, and so provides an accurate representation of the design intent. (Cambell and Hodgson, 2003). This is a significant use of CAD output and one that helps students to realise their design ideas more effectively and accurately than by the use of more traditional workshop activities alone. However, it is not always the panacea it may seem, since it requires new skills and knowledge, concerned with CNC manufacturing, selection of appropriate RP systems and materials, and post-finishing of the manufactured parts. The images in Figure 2 illustrate a range of CNC and RP manufactured parts, some to prove the functionality of a product and others to help with user evaluation.

All these outputs provide excellent examples of how a detailed CAD model may be exploited to illustrate or realise design ideas. In this respect, CAD is a great enabler for students, particularly those who do not have the skills or confidence to effectively communicate through sketches, drawings and sketch modelling activities. Typically, they are employed at the *end* of design development, and CAD has yet to be fully exploited *during* the design development:

Figure 2: A range of CNC and RP manufactured prototype parts

Digital Design - the potential of Computer Aided Designing in design learning environments

> *Teachers believed that many of the activities associated with project-based design could be, and were, undertaken using CAD technology. There is also evidence to suggest the successful adoption of CAD for post processes and outputs but the evidence to suggest that the activity of 'designing' is currently occurring within CAD is, as yet, inconclusive. (Hodgson and Fraser, 2005: 95-106).*

The more advanced implementation of CAD activities

How can CAD be employed more effectively in the activity of *designing* itself? It is possible to make use of CAD facilities that extend the use of CAD beyond just an output of the final design proposal. This includes simulating, checking and testing function or operation; re-design of parts and concepts so that the designer can ask "what if?" and assisting design development across a range of design processes.

Simple mechanisms can be assembled and tested within the CAD model so that an operation or function may be simulated. This can be relatively easy to achieve, and allows the prototype to be made with some confidence that it will be 'right first time'. This is not necessarily the case with 'sketch modelling' (e.g. use of card and pins) or 'kit systems' since they may not be well enough 'engineered' to prove the principles involved or may be restricted by available parts and components in the kit. Moreover, the advantage of re-modelling the mechanism once it has been established, allows the CAD modeller an opportunity to correct or optimise the design before prototyping or manufacturing begins.

The example in Figure 3 illustrates a simple animated toy crocodile where parts can be moved as a simple set of linked components. The exploration, analysis and optimisation of this simple mechanism is a fundamental part of the design development for this student project. More advanced animations allow forces to be applied to the CAD model so that it operates much as it would as a 'real' prototype, reacting to changes in the direction of an applied force, allowing for friction and gravity, and checking for 'collisions' between component parts. This means that the animation may be considered to be a simulation of the design idea, extending its usefulness beyond that of a simple illustration of movement.

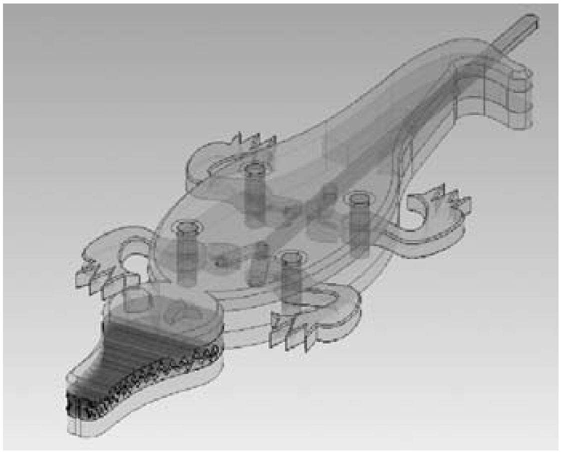

Figure 3: Linked component parts of an animated toy crocodile

More advanced simulation is available, albeit in more complex CAD modelling software, through use of Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD). The detailed analysis of FEA may be beyond the reach of non-engineers, but even a simple analysis can highlight areas of potential stress in a part when it is loaded with a series of simple forces. The FEA software calculates forces and stresses in all parts of a CAD model, based on the forces applied by the designer, and highlights these using a range of different colours. The wheel illustrated in Figure 4 may require some further consideration of its design in the areas that are highlighted by darker shading, since this is where the highest forces have to be accommodated by the wheel's spokes.

Mould flow software provides an example of CFD application which is relatively simple to use. The designer is able to specify the moulding material and how it will be applied, and the software simulates how it flow and fill

Digital Design - the potential of Computer Aided Designing in design learning environments

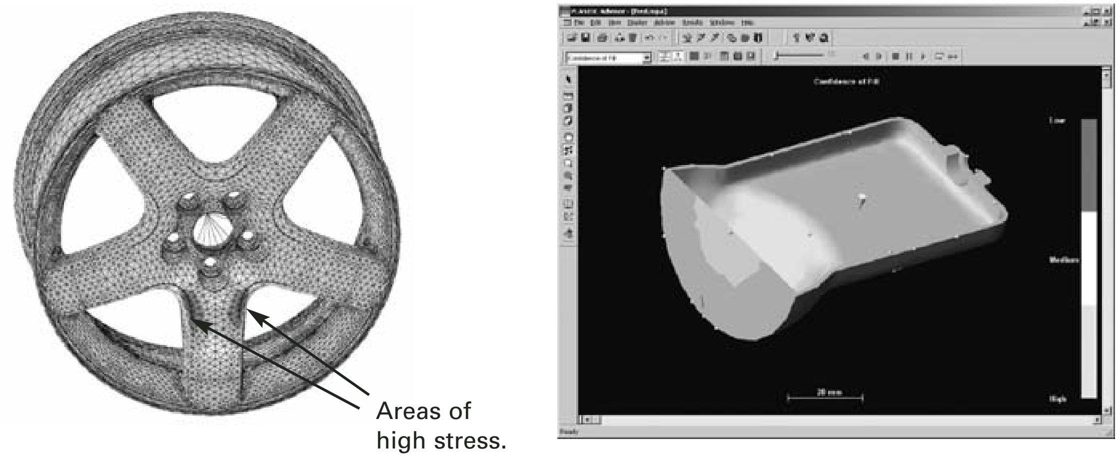

Figure 4: Example of FEA for a wheel and mould flow analysis of a plastic component

the mould. Figure 4 illustrates a CAD modelled part that is to be cast when prototyped. The software is able to suggest the best position to feed from (the 'runner' location) and also where air may be trapped (the likely position of required 'risers'). Once again, the design or prototype is improved as a result of applying CAD simulation and analysis, before embarking on other workshop activity.

In both these examples the ability to re-model or re-design the concept is fundamental to the design activity. The possibility of easily modifying CAD parts to consider new alternatives, to experiment with shape and form, and to ask a whole range of questions in the form of 'what if?' is probably the most powerful CAD related design tool. However, in order to make use of CAD in this way, it is necessary to be a competent modeller within the CAD system. Simply being able to use the feature tools (e.g. the 'revolve', 'extrusion' or 'shell' tool) is not enough, it is necessary to have an understanding of *modelling strategy or approach* as well.

Design modelling in CAD

It is necessary to consider how to model in CAD systems just as it is usual to consider how to use other modelling media like card, clay, foam etc. Equally, there is a need to develop CAD modelling capability, and the level of capability, as with other media, will depend upon the level and scope of modelling required. This is rarely addressed during the teaching of CAD modelling, yet is likely to have a significant impact on the quality of design activity undertaken with CAD. This suggests the need to consider *CAD modelling strategy* as something that should be developed and taught to students of design.

This CAD modelling capability is necessary for two reasons. The first is to enable designers to capture their 'design intent'. Whilst novice or naive CAD modellers may suggest that they can create a form more effectively in other media, effective or competent CAD modellers will compromise their designs no less than by sketch modelling or modelling in other materials. This is reinforced by previous research that considered how students approached designing activities in schools: "Some students simplified their ideas until they no longer became a challenge or a learning experience. Many made and re-made pieces of their project, altering their designs to fit their mistakes." (Atkinson, 1995:36-47). This is particularly true of those still new to modelling in any media, and research suggests that a great deal of compromise exists in most schools-based design modelling. Effective CAD modellers will be quicker, and are less likely to be worried about making mistakes. This leads to a greater likelihood of risk taking and so to a greater likelihood of innovation!

At the heart of any CAD modelling approach or strategy is the use of a 'model tree'. Sometimes referred to as a 'history tree', it lists and links all the features and their various parameters, in a hierarchy that relates whole products to parts (components) and parts to features. Hence, the use of the term 'tree'. The example illustrated in Figure 5 shows the model tree associated with part of a respirator concept. The designer is able to 're-visit' any part or feature of a part and modify its shape or other parameters. The underlying sketch or profile that defines the shape of a feature, the depth of extruded shapes and angle of revolved shapes are all easily modified. Whole features may be suppressed temporarily, re-ordered or even deleted altogether. This is a very powerful feature of a CAD modelling system which prevents the need to start afresh if design changes are required.

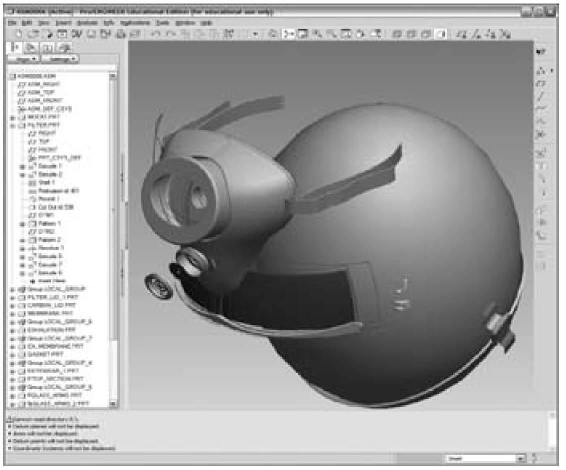

Figure 5: CAD model of a respirator concept with the associated 'model tree'

Is there a right or a wrong way to model in CAD, and what are the implications of adopting a particular strategy? There are usually many different modelling strategies that may be employed to achieve the intended outcome, and sometimes the nature of the output (e.g. a visual image or manufactured part) will help to determine the best approach. Also, the need to be able to re-design parts, during early stages of the design development, can also determine the most appropriate way to model them. The examples given in Figure 6 illustrate three ways of modelling a simple tyre for a toy truck.

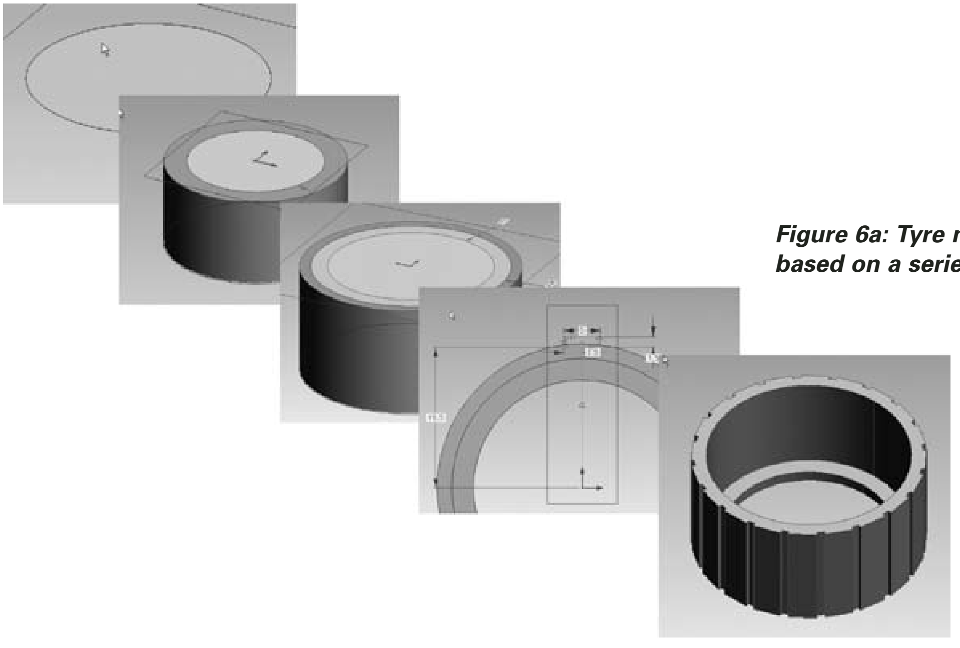

Figure 6a: Tyre modelling approach based on a series of 'extrusions'

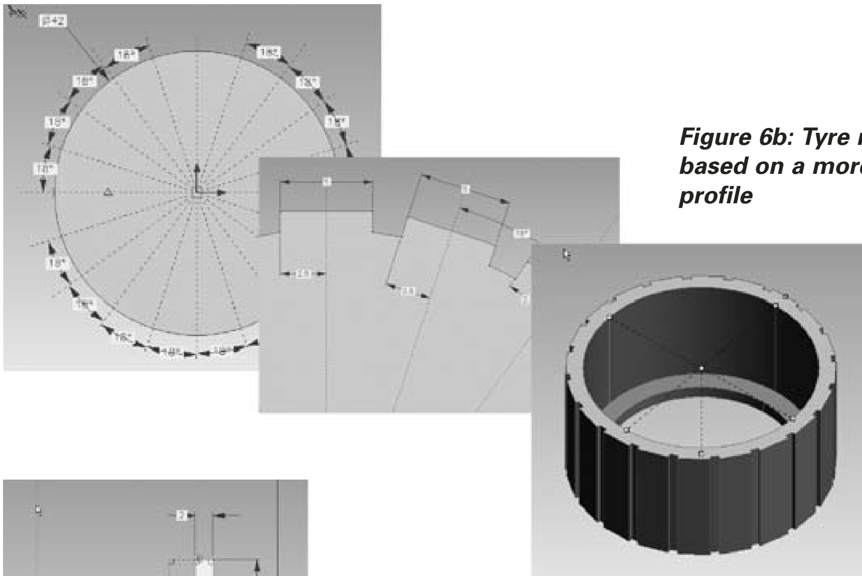

Figure 6b: Tyre modelling approach based on a more complex sketched profile

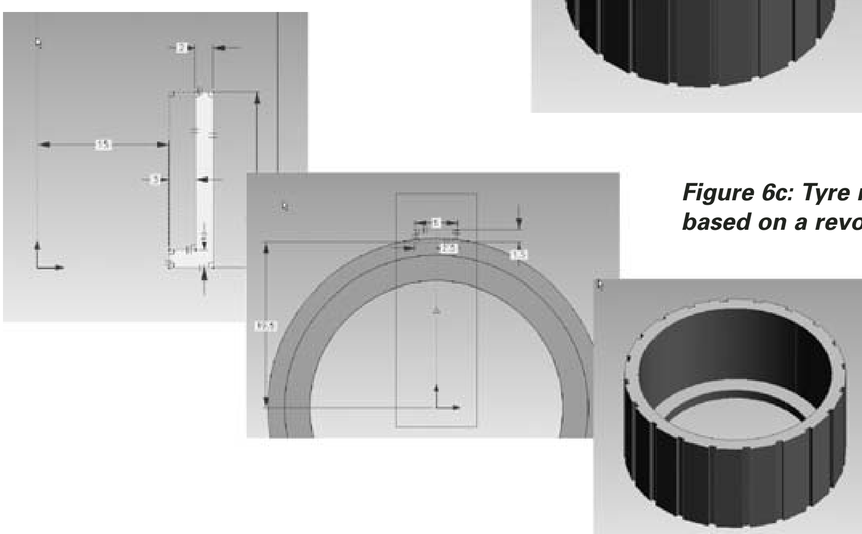

Figure 6c: Tyre modelling approach based on a revolved X-section

Those familiar with 3D CAD modelling will recognise that one strategy makes use of many circular extrusions, another uses a complex sketched profile with just a single extrusion and another revolves a cross section around an axis. In some cases the tread is 'patterned' around the outside of the tyre. All strategies achieve the same ends – an accurately modelled tyre. However, if it is likely that the tyre design is to be changed (e.g. the diameter or the number of treads in the pattern) then one of the strategies is clearly more appropriate, since it allows the designer to modify a sketched profile or the pattern parameters (via the model tree) and make the changes very easily.

This example illustrates how just one part might be modelled with a view to its subsequent modification, but if parametric modelling is also exploited, so that parts are linked together, then it becomes possible to, say, re-design the wheel and the tyre will be modified automatically to fit the new design. Such an approach is an extension of basic modelling strategy and is particularly powerful when CAD modelling is used to develop the design of complex products.

Modelling so that designs can be modified easily, or so that they truly represent the designer's intention, is something which comes with experience. The challenge for educationalists is to find ways of effectively passing on that experience so that student designers can quickly learn how to use CAD systems as a part of their design development work. There is a need to better understand the pedagogy of CAD learning, the progression of modelling skills and appropriate teaching and learning styles. On-line learning, delivered at the point of need, is a natural way to compliment computer-based activity and so may be considered to be a key way in which an appropriate level of CAD capability might be achieved. Few examples of such material exist, but researchers at the Department of Design and Technology, Loughborough University have developed on-line materials for student designers in schools and in Higher Education (HE) (Hodgson A. R. 2004).

Capturing design developments through CAD

Educationalists are also concerned with assessing the work of their students. This will often require the student to provide a record of their design development work, or more typically, a series of 'snapshots' of their development work. Contrary to the difficulties that are often associated with electronic media, the CAD model tree or history of saved files will do this naturally. CAD modellers will usually save files of their design work at critical times (e.g. just before the next critical modification or when a design iteration is considered complete). It remains only for the appropriate 'snapshots' or other information to be retrieved and viewed, or even presented in some form of folio. There is scope here for students to identify key 'design points' themselves and use selected CAD output to illustrate how their design work developed. That said, it is worth reflecting on the use of 'snapshots' to assess a holistic process of design development. In my view, at least, this has led to students, and their teachers, concentrating on the 'snapshot' rather than the whole design activity and the ability to be a good designer. The aims of design and technology education are submerged by the need to provide evidence of certain elements of design activity, often in a linear or prescribed fashion, leading to a 'formulaic' approach to design development that scores well in design assessment but fails to reflect effective design activity or ability. If the key design points, milestones or 'snapshots' are captured more naturally, as they may be via CAD modelling, then there is opportunity to allow students the freedom to engage with a holistic design programme whilst maintaining a framework for its assessment.

What are the implications for the nature of design and technology?

There have already been well-documented changes to the ways that designers design. These changes have been influenced by factors like 'time to market', 'right first time' and team-based 'concurrent design development'. CAD systems are currently marketed with such factors at the heart of their features, and practising designers already place CAD modelling high on their list of skills required in new recruits to the profession. Will design education reflect this practice? The extent to which professional design practice will influence a curriculum will depend upon the aims of that curriculum. It is likely that a design programme in Higher Education will aim to serve the needs of professional practice far more than a design programme in school-based general education. For the latter, what is learnt *through* design is likely to be of greater importance that what is learnt *about* design. There is no great need for millions of mini-designers!

This keynote has highlighted the potential of CAD to enhance design and technology education in three ways:

- to enable high quality design output in the form of visual (sometimes animated) design proposals, detailed drawings and prototyped parts;
- to simulate, test and analyse the function and operation of design concepts;
- to enable design iteration through an ability to effectively and efficiently re-design components and products within a CAD model.

These potential enhancements are clearly linked to the objectives of typical design and technology education programmes. However, will the potential of the CAD-based malleable working prototype in a virtual environment lead to better learning outcomes? There is every likelihood that it will. CAD-based output can free the student (and teacher) from the need to spend time developing skills that simply support design activity (e.g. hand rendering and multi-media modelling activities) allowing greater emphasis on the development of design concepts and ideas by utilising and applying CAD modelling strategies. Designs can be better developed through CAD simulation and analysis, so that the student prototype (they usually have only enough time to produce one, in the context of a design education programme) will be more likely to operate as they intended and function correctly. Students are more likely to undertake design modifications and to engage in the range of divergent, then convergent, design iterations that are normally associated with a process of design. They are hesitant to make modifications to their design if the need for change is only identified after hours of traditional workshop activity. The flexibility of a CAD-based design model lends itself to change, and encourages innovation and design flair by enabling students to take risks as they develop their design concepts.

However attractive an increased use of CAD may be, design and technology education will also need to respond to other influences on the curriculum. Indeed, external influences are likely to have a greater impact than the detailed considerations of CAD modelling. A good example of such an influence is the drift of manufacturing and design to China, which is likely to have a significant effect on the nature of design education in HE, and should also have some impact on the curriculum in schools. Confronting the issues that 'digital design' raises may help to fuel a wider debate about what learning outcomes are particularly relevant for students of design and technology. In addition to its potential to engage students in meaningful design development activity, CAD modelling has the potential to be an 'agent of change'. Now is the time to exploit this potential and consider how the nature of design and technology education might be changed to accommodate wider influences than those of meeting current assessment targets, and how 'digital design' can be exploited to provide an altogether more 'designerly' learning experience for students.

A.R.Hodgson@lboro.ac.uk

References

Atkinson S. (1995), Approaches to designing at Key Stage 4, in: Smith J S (ed), *International Conference on Design and Technology Education Research and Curriculum Development*, IDATER 1995, Loughborough University, UK

Cambell R. I. and Hodgson A. R. (2003), 'The impact of in house RP upon year industrial design students projects', *14th Annual Solid Freeform Fabrication Symposium*, Austin, Texas, USA

Hodgson A. R. (2004), *Pro/DESKTOP 8.0 Achiever Software*, Denford Ltd, UK

Hodgson A.R. and Fraser A. (2005), 'The impact of CAD/CAM on school-based design work', in: Norman E W L, Spendlove D and Grover P (eds) *Proceedings of the DATA International Research Conference 2005*, DATA, UK

McMahon C. and Browne J. (1998), *CADCAM: principles, practice and manufacturing management*, Addison Wesley Longman Ltd, UK