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DEVELOPMENTS IN TEACHING APPROACHES: “THE UNEXPECTED BENEFITS OF AN INTEGRATED CAD/CAM BASED MODELMAKING STRATEGY”

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ABSTRACT

This paper will examine several unexpected dividends from the implementation of broadly implemented and integrated Computer Aided Design / Computer Aided Model Making (CAD/CAMM) model making strategy. It first discusses the expected outcomes of implementing CAMM on a broad basis: high investment cost, high fidelity facsimile models, integration of Virtual and Actual 3D output, improved Health & Safety, higher speed model making output, steep learning curve (staff & students) and high running costs. The second section of the paper discusses the *actual* results of implementing CAMM as a standard educational tool within the Product Design process (PDP). The third section of the paper reveals some surprising and unexpected windfalls of CAMM implementation and uses case studies to examine the benefits they have brought to education at undergraduate level. In conclusion, the authors discuss what was learned and achieved by the adoption of an entirely new and radically different approach to design education.

Key words: Model making, CAD, CAMM, DfM, Rapid Prototyping, Virtual Prototype, Integration, Product design process, Learning, Curriculum, Education, Holistic.

1 INTRODUCTION: THE CAMM IMPLEMENTATION MODEL

Extensive 3D output is essential to the design process [1]. Like many universities in the 1990’s UWIC’s model making strategy was based on traditional soft modelling using Styrofoam and card augmented with hard, wooden, facsimile models that were either carved by hand or shaped using manually operated machine tools. Although very time consuming, this strategy had served the needs of the product design students well over the twenty years that the course had been in existence. This traditional product design process [2] used on the undergraduate programme at the University of Wales Institute Cardiff (UWIC) evolved to use 2D CAD as a means of producing accurate technical drawings in order to capture Design for Manufacture (DfM) intent and to inform the creation of facsimile models. By the end of the 1990’s this strategy was beginning to create significant difficulties. An increasing focus on Health & Safety had led to limits being set on the number of students allowed to use the workshop at one time. This was exacerbated by the post-Deering HE environment with significant increases in the number of students. At the same time, both industry and general design practices were evolving to integrate CAD [3] and it was becoming more commonplace for designers to take advantage of the high-tech *virtual prototyping* and *rapid prototyping* technologies that were emerging. It soon became clear that a new CAD/CAMM based strategy was required at UWIC if we were to address these changing needs. There was however a strong desire to maintain the well-known benefits of concept sketching and soft-modelling in the form of sketch-modelling by hand [4] that students need in order to study the subject effectively.

1.1 UWIC's Approach to the problem – the potential routes.

Initial investigation at the start of the millennium revealed that there were a growing number of Rapid Prototyping (RP) machines on the market that could facilitate an integrated CAMM methodology at UWIC. The technologies they used were divided into two distinct approaches which may be summarised under the headings of "material on" and "material off". The "material on" group included Stereo Lithography (SLA), Fused Deposition Modelling (FDM), Laminated Object Modelling (LOM), etc. Whereas the "material off" group consisted of various types CNC machine tools with the main focus on multi-axis milling machines. The "material on" group generally had the advantage of being relatively easy to use while the "material off" group were generally thought to produce more robust prototypes. Machines in the "material on" category ranged in purchase price from approximately £50,000 to £500,000, while those in the "material off" category were priced from £10,000 upwards. Materials and running costs also varied widely. Generally speaking, "material on" was more restrictive, with issues such as short shelf life, and light, time or moisture sensitive materials complicating matters further. In the light of these factors the decision was made to purchase "material off" machines. There were a number of expected ramifications from this decision.

2 EXPECTED RAMIFICATIONS

High Investment Costs: The expectation was that investment cost would be high, forcing a very gradual change with the cost being spread over a number of years.

Improved Safety: The use of manually operated workshop machine tools usually carries at least some risk of injury to the operator and it is often necessary to undertake safety training and to comply with the recommendations of the risk assessment for the equipment. Rapid prototyping machines on the other hand tend to operate automatically with any potentially hazardous moving parts hidden behind safety screens that are protected by safety interlocks. They therefore tend be inherently almost completely free of risk of injury to the operator.

Steep Learning Curve: A well established down side to the introduction of any new computer-based technology is the steep leaning curve that must be climbed before it can be used to it's full potential. It was therefore anticipated that if the students were to avoid a long and difficult training period (analogous to the traditional model making training) then the workshop technical support staff would have to carry the burden of the RP training and the consequent responsibility of operating the RP machines.

High Running Costs: A quick survey of the prices quoted by rapid prototyping bureaux suggested that the operating costs of rapid prototyping machines was significant and substantial. This was clearly of concern to an undergraduate product design programme with a small budget.

3 ACTUAL RAMIFICATIONS

This section of the paper discusses the *actual* results of implementing CAMM as a standard educational tool within the PDP.

Investment cost: The initial investment cost was minimised by the choice of technology selected. It was decided to minimise the cost of investment by initially purchasing only one, small, inexpensive 3-axis CNC router. This machine was approximately one tenth of the cost of the nearest equivalent “material on” rapid prototyping machine at the time of purchase. Following the successful introduction of this machine additional machines were purchased each year for the following five years.

Improved quality of design: Experience has shown [5] that the quality and amount of detail design work undertaken by the students using RP as part of the design process has increased significantly compared to that produced using the traditional design process. It was found that the students were able to spend more of their time engaged in the study of product design theory and practice because they were released from the burden of having to acquire the skills of using manual machine tools to make models.

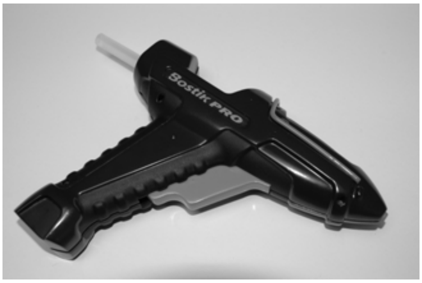

Figure 1:

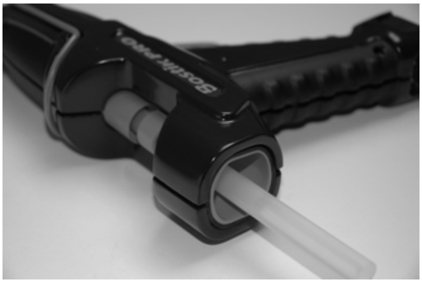

Figure 2:

Improved quality of facsimile models: The quality of facsimile model making increased significantly following the introduction of CAMM. *Figures 1 and 2* show the typical output from a “glue gun” design project using the new CAD-CAMM approach. The figures illustrate how the simplified forms that were typical of the traditional method have given way to more sophisticated, fluid, compound forms.

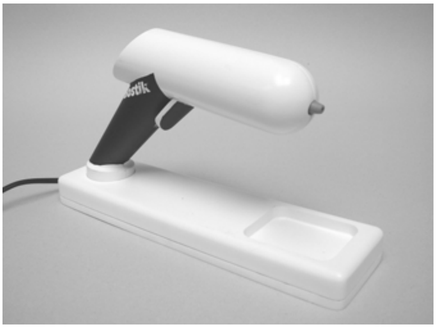

Figure 1: A glue gun model designed to suit manufacture by turning and milling.

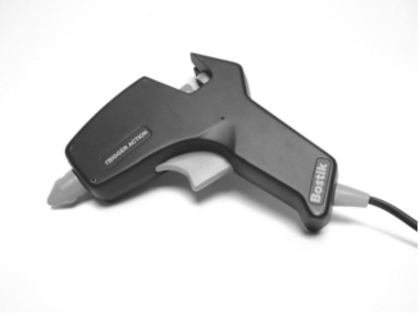

Figure 2: A glue gun designed to be made by band saw and hand finishing.

In contrast *Figures 3 and 4* show the typical facsimile model output of the traditional (manual machining) model making method. It is apparent that the simple forms of the main body of the “glue gun” in *Figure 3* have been compromised by being designed for ease of turning on a lathe, whereas the main body of the “glue gun” in *Figure 4* was clearly designed to cut to shape using a band saw and modified using hand tools.

Integration of Virtual and Real Prototyping: One particular advantage of integrating CAD-CAMM into the undergraduate product design process is that it overcomes the sometimes tenuous links between a student’s design specification (BS8888 drawings) and the associated manually made facsimile models of the traditional process. In contrast with this traditional approach the adoption of CAD-CAMM fully integrates the design and model making steps because the creation of the real model is dependant on the creation of the virtual model.

Improved Safety: The safety record of the RP machines in question is excellent with a 100% safety record i.e. no accidents attributable to these machines having been recorded in the five years since their introduction.

Steep Learning Curve: As expected there was a steep and difficult initial learning curve for the staff before the first machine could be used productively. After approximately one year it was agreed that a step by step user manual should be created that would guide anyone through the generic manufacturing processes. This guide has been refined over the years and is now used as the de facto standard that all staff and students adopt when learning to use the CNC machines for rapid prototyping. This guide is available on the department’s VLE, the “Virtual School” [6] where it is augmented by a number of supporting documents together with a series of short video clips describing the basic machining process.

Running Costs: The running (material) costs for the CNC machines that were selected compares favourably with the manual prototyping methods. The material of choice at UWIC for general purpose CNC rapid prototyping of plastic parts is known throughout the CNC machining industry as “tooling board” and is a proprietary high density closed cell, foamed polyurethane-based material. This material produces excellent results and is sufficiently robust to simulate a wide range of proposed materials. The cost of tooling board compares well with the cost of the more traditional Jellutong a specialised use close grained hardwood which was extensively employed when making models via the traditional manual route.

4 UNEXPECTED BENEFITS

This section of the paper reveals some surprising and unexpected windfalls of CAMM implementation and uses case studies to examine the benefits they have brought to education at undergraduate level.

Elimination of “Design for Model Making”: One of the major unexpected benefits on adopting an integrate CAD-CAMM methodology was the elimination of the hitherto underground, hidden, and somewhat subversive activity of “*design for model making*” [2]. The elimination of this step produced an immediate and significant emancipation of the students design ability. No longer was it necessary for the student to constrain the design of a product so that the model could be more easily made by the standard manual manufacturing techniques that were readily available.

Reinforcement of Design for Manufacture: Three-axis CNC machining has a number of Design for Manufacture (DfM) limitations when compared with the majority of “material on” RP technologies. In fact the vendors and resellers of these types of technologies frequently boast of their machines ability to product “impossible” objects i.e. objects that cannot be made by conventional mass manufacturing techniques.

Whilst this free form ability is without doubt noteworthy and intriguing it does little to constrain the designer to follow DfM guidelines. In the case of a product design student it is clearly very important that they learn the limitations of mass manufacturing technologies so that they may successfully design products that may be manufactured by them. Somewhat unexpectedly it can be argued that the limitations of 3-axis CNC machining, unlike the "material on" RP technologies, are closely analogous to those of the injection moulding, blow moulding, vacuum forming, sand-casting and die-casting processes i.e. draft angles are required in the direction of pull and undercuts should be avoided where possible. The fact that UWIC's model making constraints are closely analogous to typical generic DfM constraints is very fortuitous and is most helpful in reinforcing the learning outcomes of DfM theory lectures in that the students must now, by default, fully consider DfM limitations typical of mass manufacturing processes in order to make facsimile models of their designs.

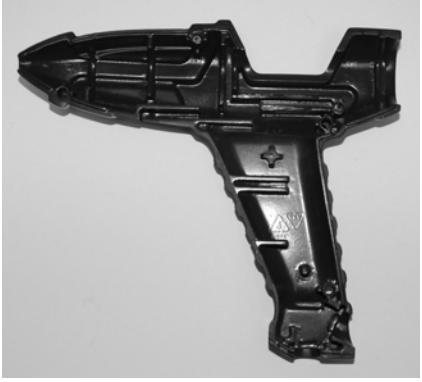

Figure 5: Internal Detail Design

Figure 6: Close up of Design for Manufacture Detail

Another unexpected benefit of the integration of CNC-based CAD-CAMM into the PDP is that the internal features of a product can be quite easily communicated in the form of facsimile models for the first time. *Figures 5 & 6* show the extensive internal detailing that fully captures the designers intended design for manufacture detailing This ability not only further reinforced the links between virtual and real prototyping, it also facilitated the implementation of detailed DfM and Design for Assembly (DfA). Up until now it had only been possible to design for and communicate DfA on a theoretical basis or via a virtual prototype.

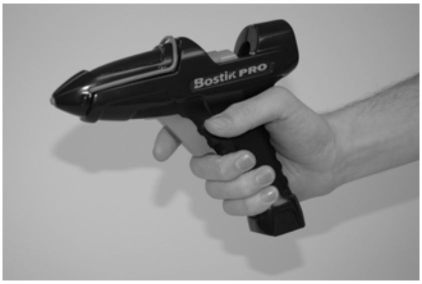

Figure 7: Fully functional working facsimile model

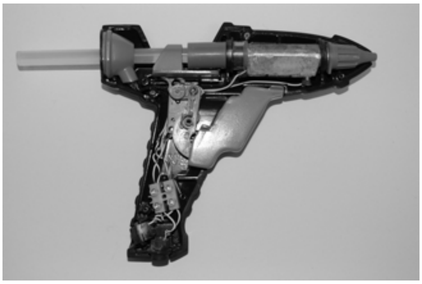

Figure 8: Standard components fitted into to CAMM model.

Fully functional facsimile models / prototypes: The ability to produce fully functional facsimile models is a significant improvement over the traditional, "appearance only" facsimile models. In some cases the existence of working models eliminates the necessity for development test rigs as the complete design can be evaluated holistically. In addition, as a consequence of the availability of high-fidelity facsimile models it is possible to perform meaningful user testing trials in order to evaluate the features of the proposed design.

5 CONCLUSIONS

- The implementation of a CAD-CAMM strategy as an integrated part of UWIC's product development process has been even more successful than was originally envisaged. In fact, last years external examiners report it was declared that this strategy "sets national standards"
- Machine tool related accidents have been eliminated.
- Workshop throughput has been increased five fold.
- The quality of facsimile model making has been significantly improved
- The activity of *"Design for model making"* [1] has been eliminated
- The Design for Manufacture (DfM) and Design for Assembly (DfA) aspects of detail design have be enhanced and reinforced.
- Working prototypes have become an everyday reality
- All these factors have significantly enriched and extend the scope of the PDP that is achievable while studying at undergraduate level hence broadening the experience of the student product designer and better preparing them for the professional product design practice.

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