A Case Study Analysis of the Application of Design for Manufacture Principles by Industrial Design Students.

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Abstract. This paper describes a case study evaluation of a module that engages students on product and industrial design programmes with the principles of Design for Manufacturing (DFM). The primary element of the module is to expose students to the constraints of a full design to manufacture process. The module explores the design of a small polymer promotional item, together with the means of mass producing that item. This is done through the process of injection moulding and students design an injection mould tool to allow the production of the promotional item out of a suitable polymer. This module brings together CAD, CNC part programming, injection moulding tooling design, polymeric material selection and production considerations. The paper will highlight the benefits of practical engagement with the DFM process.

Keywords. Design, Design for Manufacture, DFM, Manufacturing, Industrial Design.

1. Introduction

Design for Manufacture (DFM) is an essential part of the design process for all products in which a physical artefact is produced. DFM is an inherent part of engineering based design programmes but often less so for industrial design programmes. Whilst industrial designers consider materials, manufacturing processes and assembly operations there is a challenge in educating designers in the importance of DFM and in demonstrating the impact of their design decisions on manufacturing. This paper presents a case study in DFM that forms one of the core modules in the industrial design programmes offered at the Design School at Loughborough University in the UK. The paper describes the importance of DFM thinking for designers, presents a case study module and discusses how the practical application of DFM can foster an enhanced engagement with manufacturing principles.

2. Designing for Manufacture

Industrial designers develop products and systems through collection, analysis and synthesis of data guided by the special requirements of their client and manufacturer.

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They prepare clear and concise recommendations through drawings, models and descriptions and create, while working within multi-disciplinary groups that include management, marketing, engineering and manufacturing specialists [1].

Design for manufacture (DFM) is broadly the practice of designing products with manufacturability in mind [2]. Edwards [3] investigated the strategic application of materials and manufacturing process information during design process, highlighting the value of Design for Manufacture and Assembly (DFMA). However, it was also highlighted that DFMA is but one consideration within the design process and that the optimization of manufacture and assembly can often lead to conflicting requirements against other priorities such as serviceability, or more broadly, other Design for X methodologies [4].

DFMA was introduced as a method for analysing a product, seeking an improvement in manufacturing capability and ease of assembly by which the overall cost of the product may be reduced. The basic process consists of the following steps: 1) Analysing the number of parts in a product or assembly; 2) Simplifying the overall design by minimizing the number of parts for ease of assembly by redesigning at product or assembly level. 3) Simplifying the component design by using standard components, material and form shapes [5]. The reduction of components in a product is a major challenge for designers and simplifying the design and reducing the assembly time leads to reduced cost of the product. However, the number of design methods and tools available to the designer in the process of design is numerous and for many practicing designers it has become unclear when and how to apply these. According to Dewhusrt and Boothroyd if used effectively, DFMA can yield tremendous results, the least of which is that the product will be easy to assemble [6]. The most beneficial outcome of DFMA is to reduce part count in the assembly, which in turn will simplify the assembly process, lower manufacturing overhead, reduce assembly time, and increase quality by lessening the opportunities for introducing a defect. Labour content is also reduced because with fewer parts, there are fewer and simpler assembly operations.

Hand in hand with process and assembly optimization is the consideration of materials. Numerous material selection sources exist and provide up-to-date information on technical characteristics of materials. One challenge, particularly in the realm of industrial design lies in the ability for designers to evaluate materials and to utilise material selection processes in their respective product designs that support the broader design implications of materials beyond engineering characteristics. [7].

What is clear is the extent to which DFMA considerations are critical to design and benefit from consideration early in the design process.

3. The Design and Manufacturing Technologies Module

Loughborough Design School’s approach to the education of student industrial designers in DFM thinking is typified by a second year module: Design and Manufacturing Technologies (D&MT). This module is compulsory for students on both the BA Industrial Design and Technology and BSc Product Design and Technology programmes and forms one quarter of their second year. The module’s aim is to support the students in understanding the relationship between design and manufacturing. In particular, for students to experience the design of a product for mass production and all of the constraints imposed upon a designer during such a project. The module draws on many key skills taught elsewhere in the programme including visual communication, CAD/CAM, individual and group working.

The module is structured around two main elements. The first is a broad grounding in materials and processes, delivered by Loughborough University's School of Aeronautical, Automotive, Chemical and Materials Engineering. The second is a semester long design to manufacture project that revolves around the process of injection moulding (IM) delivered by the Design School.

The remainder of this paper will explore the use of the injection moulding project element of D&MT as a key pedagogic approach in the education of DFM to Industrial Designers at LDS.

3.1. The Injection Moulding Project

The injection moulding project brief requires the students to design a small, promotional, give-way polymer product ('widget') and then the injection mould tool that would be used to manufacture that item. The premise of the module is to firstly expose the students to a design process in which DFM is an explicit element and in which the consequences of their design decisions on manufacturability are immediately apparent. Secondly, the project allows students to gain hands-on experience of a very common mass production technique.

The exact nature of the widget design is not a priority for the module though the students are required to consider an appropriate promotional opportunity and to ensure that the widget has a desirable function to justify its use by the recipient and maximise the promotional opportunity. Furthermore the students must meet one or more of three requirements, provided to ensure the students include sufficient development challenges in their design:

1. The widget has more than one part that fits together to meet a functional requirement
2. The widget uses a donor part(s) from an existing product to provide a functional requirement and / or to upcycle the part
3. The widget acts as a replacement part for an existing product to provide customisation, personalisation or enhanced functionality.

The students then undertake a four week project to design their widget, and then design a prototype injection mould tool in order to manufacture their widget. The requirement for the submission includes a folio of design development consisting of sketch and CAD modelling, mould filling simulation and engineering drawings of the mould tool. Figure 1 shows sample pages from an exemplar design folio from this phase of the project.

A number of constraints are presented to the students to challenge their DFM thinking and to ensure the projects are feasible when they ultimately move to the group manufacturing phase. These include:

- The mould typically consists of two aluminium blocks 150 x 100 x 25mm
- The cavity must leave a material allowance of 5mm from each wall
- The maximum shot weight is 28g of polymer
- Students have access to four polymers including three thermoplastics and one elastomer
- Machining of cavities and inserts is restricted to 2.5d

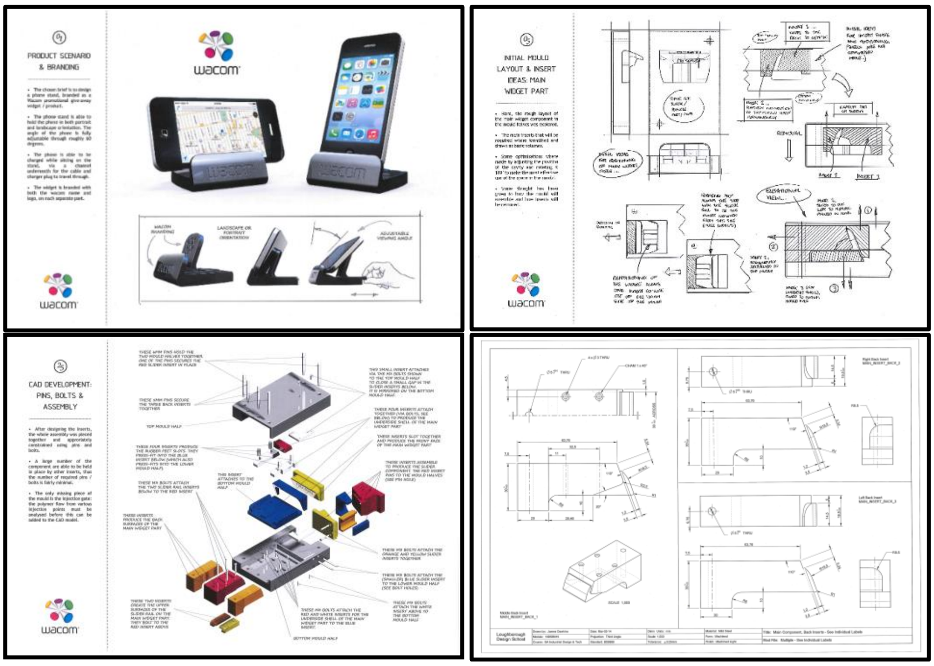

Figure 1. Injection moulding project first assignment folio: sample pages. James Dawkins, Loughborough Design School 2014.

Over and above these constraints, students must also work to the resources available in the School including the capabilities of the manual milling machines and lathes, and CNC milling machines and their corresponding tooling.

The students undertake this part of the project supported by lectures, individual design tutorials and practical workshops. In addition they draw on their skills taught elsewhere including: design process, visual communication including hand sketching, and CAD, their understanding and practice of manufacturing within the school and in engineering drawing.

After the submission and assessment of this first phase of the IM project, students form groups of typically six students and select one of their projects to take into the group manufacturing phase. Students are encouraged to select projects that are manageable and reflect a range of processes to balance workload and to provide the broadest educational content. The students then undertake a five week project to manufacture their mould tools and inject their widgets. The requirement for the submission includes a complete mould tool, an injected widget, a folio of updated engineering drawings reflecting any design changes made and a display board communicating their project to an external audience. Figure 2 shows an exemplar mould, widgets and display board from a previous group from this phase of the project.

The students undertake this part of the project supported by tutorials to help them refine their design based on feedback from the first phase and extensive technical support in the workshops.

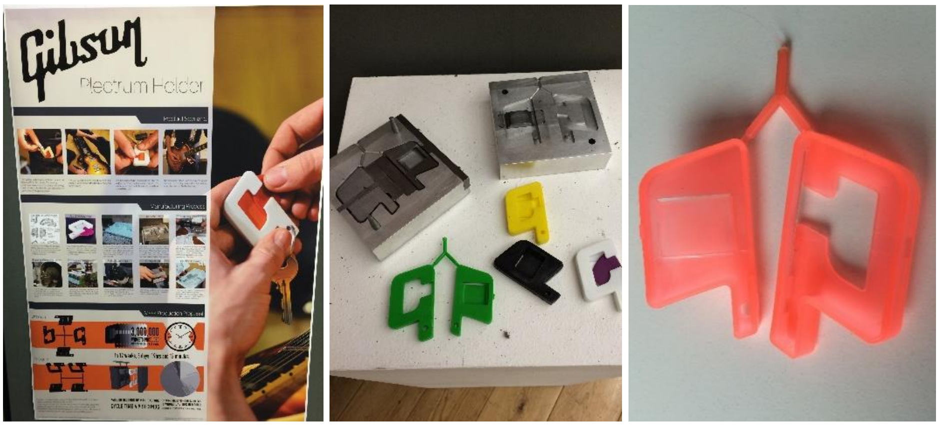

Figure 2. Injection moulding project group assignment submission: display board, mould tool and widget. Charlotte Bush, Tony Elkington, Rebecca Leatherland, Milan Madge, Ben Shearly and David Smith, Loughborough Design School 2014.

4. Discussion

Based on student module feedback, external examiner reports and responses from prospective employers the D&MT module is very well regarded. It is considered unique in the UK in providing students an experience of the full process of progressing from initial design concept through to (an approximation of) mass produced item. In gaining this experience the students are required to bring together many elements of their design education to realise a comprehensive DFM project.

Whilst the Industrial and Product designers are exposed to a range of learning opportunities that include materials and processes, the majority of this teaching is theoretical and somewhat detached from the design experience they gain. The programmes at LDS are very much design-and-make focussed, however the manufacturing element is likely to be based around prototyping techniques using modelling and fabrication approaches together with 3D printing, with materials often selected for their ease of working or availability, to achieve a prototype to meet the specific requirements of their assessments be they appearance models, ergonomics prototypes, or evaluation prototypes. Thus, industry level manufacturing considerations are inherently divorced from their practical experience. The IM project addresses this limitation and allows the students an opportunity to experience the use of an industrial process with industrial polymers in the design and manufacture of a product.

In experiencing the iterative design process of both their widget and their mould tool the students are faced with practical design constraints. Their creative freedom is inherently impacted by the requirements imposed upon them. This is an important learning opportunity within the module and reflects the very real world constraints that students will face in employment. Whilst design constraints feature in many of the design briefs that the students will experience they are often constraints presented and well understood from the outset of the project. By contrast, many manufacturing issues are emergent, only becoming fully apparent once the mould tool design has begun. This encourages the students to iterate both the design of their widgets and their moulds in a simultaneous engineering manner.

Another significant learning opportunity of the IM project is the detailed exploration of form and of (relatively) complex assemblies in both 3D and 2D formats on paper, in CAD, and with physical components. Again this allows the students to begin to rationalise concepts and fundamental geometrical relationships that are inherently theoretical when sketched on paper or modelled CAD but become very real when they have to be manufactured. This conversion between 2D and 3D in these different formats is an essential skill in many of the elements of design that are often taken for granted and are often taught in isolation. The IM project provides an opportunity to draw together these synergistic skills and approaches in a project that provides an end outcome that makes manifest all of the design decisions taken and highlights the inherent advantages and disadvantages of those.

The IM project has been running now for more than fifteen years, during this time it has been clearly demonstrated that industrial design students gain significant understanding of the relevance and application of DFM skills through an opportunity to apply them in a project. The ability to combine both design and manufacturing in an iterative process provides learning opportunities that are much more immediate and tangible than more theoretical approaches. However, it should be noted the cost of resourcing this project. Providing this type of experience is costly to LDS in both time and resources. Significant workshop equipment and technical support is required throughout and providing this experience to over 150 students each year requires significant staff support in both teaching and assessment.

5. Conclusions

DFM is a fundamental consideration for all designers and forms a core part of design education. For industrial designers there is an inherent challenge in communicating the impact of DFM considerations without exposure to the real-world impact of their design decisions. This paper outlines an undergraduate module in the Design School at Loughborough University that provides an analogue of that experience by allowing students to undertake a full design to manufacture project utilising DFM principles in the design and manufacturing of a promotional polymer product and the mould tool to product that product. The module serves to highlight the importance of DFM thinking and gives first-hand experience of manufacturing constraints on the design process.

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