COLLABORATIVE DESIGN PROCESS OF A CONFIGURABLE PRODUCT

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Abstract: The demand to fulfil a wider range of customer requirements and the need for customisable products increases constantly. The product life cycle as well as the lead time for product development shortens. Collaborative product development enables faster development of complex products but challenges the communication and the data management. Digital design methods and processes enable the collaborative development and decrease the need for expensive prototyping. In this research, collaborative product development for custom made products is studied. A case study of a configurable bathroom faucet was performed. The digital design for manufacturing using sand casting and laser based additive manufacturing as alternative manufacturing technologies were studied.

Key words: configurable product, product development, parameterised modelling, additive manufacturing, laser selective melting.

1. INTRODUCTION

To fulfil a wide variety of customer requirements and to shorten the lead times are important today. To compete with the developing economies European industry has to invest in the product development and in designing high-end and unique products. Modularity and configurability reduce the amount of required components, speed up the production and form a base for customizability.

1.1 Background

Product development projects are usually collaborative. The design can be decentralised and the communication between different disciplines is challenging. The up-to-date information must be available for all of the participants. Traditionally, prototypes are built for different purposes but it can be time-consuming and expensive. Simulation decreases the need for physical prototypes and speeds up the process. In addition, the design can be optimised with virtual prototypes without manufacturing costs. Digital design can be used to help faster development of products. Computer aided design (CAD) allows fast representations of ideas, makes the collaborative design of complex products and product families possible and enables the creation of documents and files for digital manufacturing. Simulations of virtual prototypes are effectively done by computer aided engineering (CAE) tools. Product data management (PDM) systems attend to store and distribute the huge amount of information created during the development project. To test the collaborative digital design process an electrical bathroom faucet was used as a case study.

Laser based additive manufacturing (LBAM) is a technique in which 3D shaped products are manufactured from fine grained metal powder to solid form by melting the powder layer by layer with a laser beam. The shape of the product is taken directly from a 3D CAD model and the process changes the digital model to a solid metal part[1]. The development of user-friendly software and quick and easy transformation from CAD drawing to finished part have made the LBAM process interesting for
prototyping and modelling. A wide pallet of materials and improved quality of the parts has decreased the gap between end product and parts manufactured with additive manufacturing machines. Nowadays parts are directly manufactured and the method is not just used for manufacturing prototypes and models. Growing trend is towards making parts for small batches and end-use functional parts with long-term consistency [2]. Typical application fields for additive manufacturing are concept models, light weight structures and diverse applications used in mechanical engineering. For turning the LBAM process into production for functional parts with long-term usability, the method needs to be reliable, needs to ensure mechanical properties and geometrical accuracy of the workpiece. Additionally, the process needs to be fast to ensure economical performance [3].

1.2 Research problem
This paper in the field of engineering design discusses designing a configurable product by digital systems in a collaborative product development project. The initial challenge in designing an electric faucet is to involve intuitiveness and user-friendliness. Also, data transfer and communication between the designers with different professional backgrounds need to be studied. The requirements of different manufacturing technologies have to be taken into account in configuring the CAD model. The challenge of a configurable design is to maintain all the requirements with each configuration throughout the design and manufacturing process.

1.3 Aim of the research
The primary targets of the case study were to design a configurable CAD model of an electric bathroom faucet and to study the effect of the selected manufacturing method on the design. In this research configurability was defined as the ability to parametrically modify the design of the model. The secondary target was to design the CAD model so that the manufacturing documents including files for manufacturing could be produced for each configuration.

1.4 Scope of the research
Requirements and challenges of other fields as well as the whole product development project are reviewed from the engineering design point of view. The development of the faucet is limited to the configurable design of the spout. Existing internal components are used. Requirements set by the selected manufacturing methods on the design are studied but the manufacturing of the product is excluded.

2. METHODS
An existing electrical bathroom faucet was used as a reference. During the design of the configurable faucet the research team used the product development process defined by Ulrich & Eppinger [4].

2.1 Product development process
The process of the faucet development project is divided into five different stages. The phases are planning, concept development, system-level design, detail design and testing and refinement. The planning phase is considered to be performed before project started and is not discussed here. The process is examined from the engineering design point of view. The focus was defined during the concept development phase. The aim that was set in planning phase was to design a configurable electric bathroom faucet, to build prototypes and to compare the manufacturing techniques from the design and manufacturing points of view. Configurability was defined in the concept development stage as the ability to parametrically edit the size and external shapes of the faucet spout maintaining the original design outlook.

Concept development
The structure and the internal components of the reference electric faucet were
investigated. The components of the reference faucet are shown in Fig. 1.

Fig. 1. The spout and the internal components of reference bathroom faucet.

These internal components were decided to be reused in the new faucet design. The components were modelled with Solid Edge software. The team used the CAD documents as a reference in the concept development phase with Rhinoceros [5] as well as in the system level and the detailed design stages with Pro/Engineer Wildfire software. The 3D models were transferred into these systems in STEP format [6]. The use of the existing components set restrictions to the faucet spout design. These components had to fit into the new spout. The positions and the interfaces of the water feed pipe, the thermostat controller, the sensor, and the fitting screw were fixed. Also the thread of the nozzle was fixed. Another requirement for the spout was to design the outlook so it would be intuitive to use. The outlook of each configuration has to guide the user to put the hands into the operation zone where the sensor recognizes the hands and to where the water jet is aimed at.

Fig. 2. Proposed concept models created with Rhinoceros software.

The industrial designer of the research team proposed several configuration models and one was selected for the design process. Two examples of the concept models are shown in Fig. 2.

System-level design

In this case the system-level design can be considered to be divided into two steps: gathering precise information and CAD modelling. The requirements set by the two selected manufacturing methods, sand casting and laser based additive manufacturing (LBAM), were studied. The pattern for sand casting was designed to be manufactured by 3D printing and the core box by NC milling.

The CAD modelling started in Rhinoceros where the surface model of the final outlook was created. The Rhinoceros model was then transferred into Pro/Engineer in STEP format. The modelling had to be started from scratch in Pro/Engineer because the parametric configurability had to be enabled (Fig. 3).

Fig. 3. Parametric model of the chosen concept. Height and Length can be modified by the design algorithm.

The imported STEP geometry was used as a reference for precise modelling. The profiles were approximated as lines, constant radius arcs and splines with minimal control points. Certain geometric entities were constrained to the STEP geometry. Other entities were first constrained to the STEP geometry to maintain the original design and the constraints were then removed to allow the parametrical editing.

Based on this parametrical solution, a simple CAD model without any internal features was modelled. The demand for ability to modify the size of the spout was set earlier. The size could be edited by changing two parameters: height and
length. To avoid the change of the desired outlook when editing the parameters certain dimensions and geometric entities were set to change relatively to these parameters. If the length of the spout increases, the point where the water jet is aimed at does not increase as much but remains at the hand washing area. Also, a larger spout may look thinner as a smaller one so several dimensions were related to the length parameter with equations to maintain the original outlook with different parameter values.

The purpose of the prototype was to make discussion and the design of internal features easier, to see the design physically and to test sand casting. It was binder jetted into two halves to see the internal space and to avoid using cores in possible casting tests.

The research team decided to build two separate CAD models, one for casting and one for LBAM to optimise the model for both methods. Required tapers for casting and overhang supports for LBAM set major requirements for the CAD models. The model designed in the system-level served as a master for both models. The CAD models of internal components were used for designing the interfaces and fittings of the spout.

A product model and a billet model were needed for both casting and LBAM. The product model had all machining and was the CAD representation of the final product. The billet model did not have the machining included. It is a model of a billet produced by casting or by LBAM. The cast billet also had extra features, such as offset taper faces and fillets, which did not exist in the product model. The product and the billet features were modelled to the same CAD file and grouped into machined and billet groups. Additionally, a core box and a pattern had to be designed for the cast spout. To design them associatively a CAD model of the core is needed.

3. RESULTS
3.1 Design for casting

The casting plan was designed collaboratively with casting experts. The joint line is the symmetric plane of the spout (Fig. 5). The casting gutter was designed to be connected to the water feed mount of the spout.
The casting plan set requirements for the tapered surfaces. All taper angles were set to 3°. The external surfaces of the cast billet were offset before tapering in Pro/Engineer to take the required machining allowance and tolerances into account. Only the free hole for the nozzle was designed to be cast but the nozzle thread and all other holes were machining features. The machining features are illustrated in Fig. 6.

3.2 Design for laser based additive manufacturing

Manufacturing orientation (i.e. orientation of powder spreading unit) is important in LBAM. Supports were required to be built between the spouts and the platform. Overhang structures, if their building angle is less than 45°, need an additional support structure because powder material is then not any more able to support manufactured parts and droplets are formed to outer surface. The spout was planned to be built in upside down position. This way the orientation was optimal for minimizing overhangs. The only overhang forms to the hollow water chamber. The internal parts of the chamber were wedge-shaped so the restriction on the structure by the building angle was taken into account.

The machining features are illustrated in Fig. 7. The counterbore will be machined after LBAM because the connection with the water feed pipe has to be leak proof. Diameters of holes located perpendicular to the manufacturing direction will not be built precisely because of the bonus-Z effect, which is the unwanted growth of the part in the z-axis and the part is therefore, out of tolerance. It occurs when the laser energy penetrates beyond the first layer of the part and melts the unsintered powder below the part boundary [7].

3.3 Comparison of the models

Comparison of time spent on design for sand casting and LBAM are represented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Casting</th>
<th>LBAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consulting</td>
<td>11 h</td>
<td>7 h</td>
</tr>
<tr>
<td>Configuration model</td>
<td>21 h</td>
<td>14 h</td>
</tr>
<tr>
<td>Family instances</td>
<td>2 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Tools</td>
<td>7.5 h</td>
<td></td>
</tr>
<tr>
<td>Trail files</td>
<td>5 h</td>
<td>2 h</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>46.5 h</td>
<td>25 h</td>
</tr>
</tbody>
</table>

Table 1. Time spent in hours on design for sand casting and LBAM.

The time to design the configuration model consists of modelling the configurable product model and the associative billet model. The reason for designing the family instances is to generate and to select customized models from the product family. The associative core, core box and pattern models were included in the tool design. The total time spent on design for casting was 46.5 hours and for LBAM 25 hours.

4. CONCLUSION

The current CAD systems are effective in designing complex and configurable products. The used software tools in this research were not the latest versions but
still the utilization of them in a collaborative digital design process was successful.

The import of CAD data in STEP format from Rhinoceros to a parametric model in Pro/Engineer was not successful. The transformation of the geometry to a parametric model needed extra work. The new versions CAD software also from other vendors may provide a solution to this problem.

The design for casting was more time consuming than the design for LBAM. A technique which requires tool design needs more time. In this case the geometry for the casting was more complicated which can be seen in the consulting and configuration model times. Designing the internal geometry of the cast spout as well as planning the casting orientation took their time. The longer time spent on the trail files of the cast model is explained by a bigger amount of parts to be scripted. The geometry of the LBAM spout is simpler. The CAD modelling for the LBAM does not need as much skills because no tools are required but understanding of process limits is required.

5. ACKNOWLEDGEMENTS

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6. REFERENCES


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