Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 37 (2015) 260 – 264

www.elsevier.com/locate/procedia

CIRPe 2015 - Understanding the life cycle implications of manufacturing

Enabling Lean Design Through Computer Aided Synthesis: The Injection Moulding Cooling Case

Juan M. Jauregui Becker*, Wessel W. Wits

Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands

* Corresponding author. Tel.: +31-53-4893101; fax: +31-53-489-3631.E-mail address: j.m.jaureguibecker@utwente.nl

Abstract

This paper explores the application of Computer Aided Synthesis (CAS) to support the implementation of Set-Based Concurrent Engineering (SBCE) and Just In Time Decision Making (JIT-DM), which are considered as two of the cornerstones of the Lean Design method. Computer Aided Synthesis refers to a next generation computational tools that automates the process of generating candidate solutions to ill-defined design problems. The design of injection moulding is used to demonstrate the rationales of the approach. This is a well-known complex and time-consuming industrial design process that generally involves rework time as a consequence of the design iteration loops performed between mould design and part design. The paper presents a tool to automate the design of cooling systems and shows how it supports the application of SBCE and JIT-DM to enable an increase in design process efficiency and effectiveness. The paper finishes with a general discussion on the enabling role that CAS tools have on the implementation of lean design practices.

Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing

Keywords: Computational Synthesis, Lean Design, Injection Molding

1. Introduction

Given current high market dynamics, design teams need to make design changes constantly and adapt to new requirements at the smallest efforts possible as the design process progresses. This has risen one of the main current challenges affronting the product development process: balancing the search for innovative solutions while guarantying a short design time. An approach that is gaining force for dealing with this challenge is Lean Design (LD) [1]. LD is a practical method to accelerating time-to-market through aggressive waste elimination in all phases of the design process [2]. Toyota, the company that created this method, has presented productivity rates up to two times better than its rivals [3]. In LD, effectiveness and efficiency are achieved by the continuous application of two principles, namely, Just in Time Decision Making and Set Based Concurrent Engineering. Just in Time Decision Making (JIT-DM) consists on taking decisions proactively by acting on the level of information readiness of a given design phase [4]. Set-Based Concurrent Engineering (SBCE) consists on having designers reason about, develop and communicate sets of feasible solutions concurrently and with certain independence [5].

This paper argues that a technology that can be used to support the operationalization of these principles is Computer Aided Synthesis (CAS). CAS supports the synthesis phase of a design process through the algorithmic creation of designs [6]. The aim is to leverage computational speed and depth of calculation to reduce the tedium of human designers and augment the process of searching the space of alternatives for preferred solutions [7]. The goal of this paper is to discuss the potential that CAS offers to enable lean design principles.

The paper illustrates this at the hand of the design process of injection moulds. Given the amount of components, physical phenomena and processes involved, the design of injection moulds is still considered a complex

Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing
doi:10.1016/j.procir.2015.08.057

and time-consuming activity, especially if one contemplates the miniaturization and extended features of modern products. Current computer tools to support its design focus on process simulation and optimization of some of its features (i.e. parting line definition, filling behaviour, cooling time). Under this paradigm, a human designer has to create the initial design proposal from where computer aided engineering and optimization methods can be applied to achieve further improvements. As a consequence, designing injection moulds remains time consuming and the quality of the proposed solution -even after optimization- is strongly dependent on the initial proposal generated by the designer. By implementing some design tasks of the injection moulding design process into CAS tools, SBCE and JIT-DM practices can be made operational, resulting in a more agile overall design process, as it becomes more efficient, more effective and more resilient to unexpected changes and market disturbances.

2. Computer Aided Synthesis (CAS)

The Lab of Design, Production and Management of The University of Twente, The Netherlands, has been researching the development process of Computer Aided Synthesis (CAS) tools over the past 15 years. CAS is our particular vision on how to implement Computational Design Synthesis methods to support industrial design environments. Computational Design Synthesis (CDS) methods support the synthesis phase of the design process through the algorithmic creation of designs [8]. The goal is to utilize computational speed and depth of calculation to minimize the tediousness of routine design and increase the number of candidate solutions. Then, the selection of the most appropriate design solutions is done by searching the space of alternatives for preferred solutions. In this sense, the aim of CDS is not just to find the best possible solution to a design problem, but to generate spaces of feasible solutions. It can be argued that it follows rather the logics of constrain solving than of optimization (although optimization algorithms might be used to generate solutions spaces). CDS as a method also differentiates itself from traditional optimisation in that the goal is broader, as it also captures, emulates and utilises expert knowledge to generate solution spaces from ill-defined problem formulations [7].

CAS tools base the generation of candidate solutions on CDS methods, and expand this core functionality with knowledge management, requirements engineering and solution space exploration features [6]. The scope of CAS extends the concept of searching for optimal designs with methods for creating solutions to propose to the optimisation, as indicated in Figure 1 [9]. The figure shows that a design is analysed to determine its qualities. For this task, Computer Aided Engineering software is commercially available, for example, to calculate the cooling time in the case of injection moulding design. Optimization makes small changes in the design, and its aim is to improve the quality of an existing solution. To do so, the designer has to start with the fully defined model of a design and select an optimization objective. CAS provides the designer with the landscape of feasible solutions given a predefined set of constraints. As a consequence, the role of the designer becomes one of determining constraints, assessing with a CAS tool the space solution and navigating the solution space for finding a solution that meets her/his own implicit constrains and design criteria. Furthermore, gaining insight in the solution space allows the designer to change the design requirements and design constrains with the goal of steering the solution space towards other quality regions. As it will be seen in Section 4, these properties are in line with the principles of lean design described in Section 3.

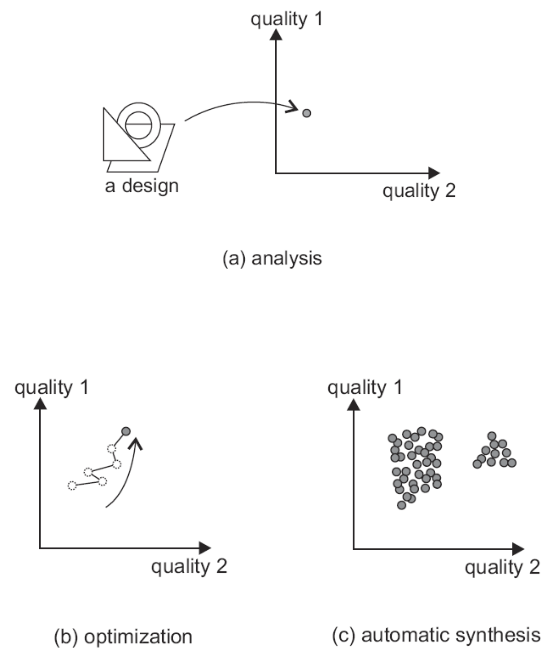

Fig. 1: Type of tool support to design [9]

3. Lean Design

Lean Design is a practical approach to accelerating time-to-market through aggressive waste elimination in planning, resource management, design control and interdisciplinary communication. As in manufacturing, lean design has the goal of eliminating waste such that value can be maximized. However, as the nature of the design process is intrinsically different than that of manufacturing, the concept of value has its own particular meaning within the lean design approach [1]. As a consequence, the leaning principles are different than in manufacturing too. In lean design, the design process creates two different types of value: operational systems (e.g. an injection mould) and usable knowledge (e.g. knowhow for designing a new mould in the future in less time and of better quality) [3]. When these values are created in an efficient and effective manner, profitable operational streams emerge. In lean design, effectiveness and efficiency are achieved by the continuous application of two principles, namely, Just in Time Decision

Making (also known as the pull-cadence principle) and Set-Based Concurrent Engineering [3].

Just in Time Decision Making (JIT-DM) consists on taking decisions proactively by acting on the level of information readiness of a given design phase. JIT-DM rest on the base idea that information processing entities (i.e. engineers) can act the most effectively when the information batches required for carrying out those decisions are fully available. Consequently, efficiency also increases, as the decisions made are more effective and no time is wasted on readapting afore made erroneous ones. Set-Based Concurrent Engineering (SBCE) consists on having designers reason about, develop and communicate sets of feasible solutions concurrently and with certain independence. Then, as the design process proceeds, solutions are evaluated and dismissed based on additional information coming from different disciplines and stakeholders.

This design approach rises the designers awareness on what is possible and what is not, have clear views on the technical feasibility boundaries of other design perspectives, and reduce design time by focusing on selecting feasible solutions rather than focusing on adjusting one that meets the original requirements. Furthermore, by continuing further design steps with a set of solution covering different design options rather than a single one, the robustness and stability of the design process is increased, as future changing requirements can be seen as moving design constraints that narrow down the space of feasible solutions without requiring complete redesign time consuming loops.

4. Lean Design Through Computer Aided Synthesis

The basis of applying SBCE and JIT-DM is to enable concurrent design by generating sets of feasible solutions that can later be narrowed down by superposing different stakeholders' criteria in the form of design constraints. The traditional multi-objective design paradigm in product development processes follows an "optimization" type of mind-set. That is, setting up design requirements, constraints and an multi-objective function first, and then solving the design problem by proposing candidate solutions that can be optimized further to meet the desired criteria. In contrast to this approach, the SBCE logic is one of first generating sets of feasible solutions for each quality measure, and then combining the resulting sets and applying the design constraints to select the most appropriate solution. When no feasible solutions are found at the intersections, four requirements engineering practices can be chosen to be applied: (1) negotiate new trade-offs between conflicting goals and constraints, (2) remove and relax design constraints to accommodate the determined solutions, (3) focus the solution generation on specific zones of the solution space with more chances to find non conflicting solutions, or (4) redefine the requirements based on the past experience and start all over again.

The functionality of CAS supports this design principles in several ways. Firstly, CAS enables designers in entering their own knowledge rules to steer the generation process. Therefore, as the design is being detailed, new knowledge is added through the knowledge management feature such that it can be considered in the generation process. Secondly, CAS can generate solution proposals for any combination of requirements. This has a two folded meaning. On the one hand, different combinations of known vs. unknown variables can be used to specify requirements. On the other hand, the variables chosen for specifying requirements can have different values and input functions (e.g. probabilistic functions). For the designer this means that at any moment he/she can change requirements on one of these two levels and assess the solutions generated. From a lean point of view, such a flexibility enables the application of the four requirements engineering aspects of SBCE described previously in this section. Thirdly, CAS generates feasible sets of solution proposals and provides the user with solution space navigation support to enable the designer in finding the right solution. In relation to lean, this means that the designer is enabled in generating sets of solutions and using constraints to narrow the solution set to find a feasible solution. Furthermore, stakeholders and designers from different disciplines can explore the solution set concurrently, which results in time efficiency.

The following section describes how the implementation of CAS to support the design of injection moulding cooling systems results in the application of SBCE and JIT-DM enabling a more concurrent and agile design process.

5. CAS in Injection Moulding Cooling Design

The design of injection moulds consists of six main processes, namely, (1) splitting of geometry, (2) slit-line definition, (3) injection point determination, (4) moving parts design, (5) ejector pin design, and (6) cooling system design [10]. Figure 2 shows in detail the different tasks that are undertaken during hits phases. During the geometry splitting phase, the product to be moulded is virtually divided in several parts. Once this is done, the split line is defined to identify the core, cavity and eventual sliders of the mould. The injection point definition consists of defining the points were the mould will be filled in with the hot the polymer. At this point, the mechanisms required for moving the sliders are designed and the geometry and places where ejector pins are located are fixed. Finally, at the end of this process, the cooling system is designed.

Cooling design is of paramount importance for the injection moulding process because it determines to a large extend the final product quality as well as production time. However, cooling design is done at the end of the mould design process. As consequence, it is constraint by the results of the upper design decisions, leaving small room for optimal cooling systems. The major constraint imposed to cooling design is the complexity of the mould geometry after the first design steps have been worked out. Sliders, ejectors pins and other mould moving parts constraint the mould volume so much, that an optimal cooling is hardly feasible. Therefore, from a design process point of view, cooling system design can be improved by performing it concurrently with the design of sliders, ejector pins and other moving parts, as indicated in Figure 2. Since present human design consumes long times, doing so is not realistic.

In order to support this, a CAS cooling designer was developed. The method and algorithms described in [11] specify in more detail the rationales of the CDS method this tool is based on. As Figure 3 shows, SolidWorks© [12] is used as interface for modelling the 3D mould parts as well as for allowing the user specify the characteristics of the mould being designed. For example, the user can specify the different types of parts (core, cavity, slider, plastic part and ejector pins) as well as different types of surfaces (e.g. surfaces for placing inlets and outlets, hot surfaces, surfaces that cannot be drilled, etc).

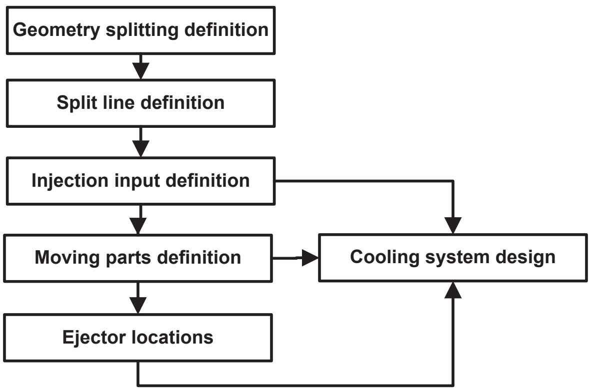

Fig. 2: Cooling design replacement in mould design process

Once the mould characteristics and geometry are specified, the software can be set to generate cooling solutions. The solutions generated for the telephone casing in Figure 3 are shown in the exploration tool in Figure 4. As the figure indicates, each point represents one entire cooling solution. The designer can then choose the solution or solutions she/he consider more appropriate by formulating trade-offs between different performances. For example, longer cooling circuits that follow more appropriately the part shape result in better cooling performance at the expenses of high manufacturing costs.

By automating the cooling system design, designers can assess cooling options at an earlier phase of the overall injection moulding design process. Doing so allows them to determine optimal cooling options without the constraints imposed by the moving parts and ejector pins. In fact, cooling solutions will act as soft constraints for the design of moving parts and ejectors pins.

By implementing this tool, expert knowledge is made available in a way that it can be quickly be operationalized during a design process. Furthermore, decisions are standardized assuring consistent design criteria. By generating solutions spaces, designers can also make the proper trade-offs between several aspects, as for example injection pressure and injection time.

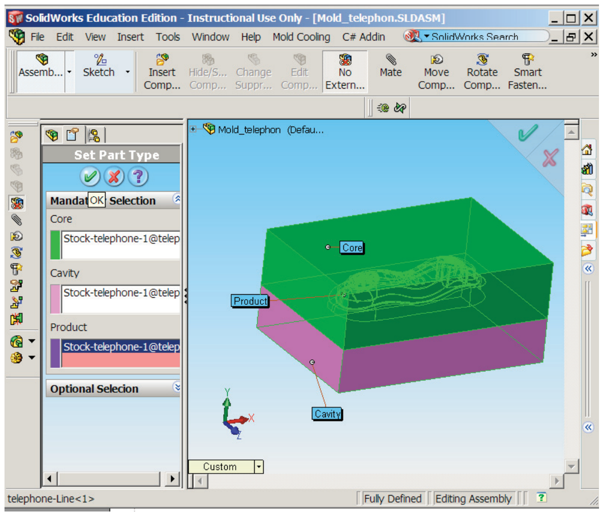

Fig. 3: User interface for requirements specification of cooling designer.

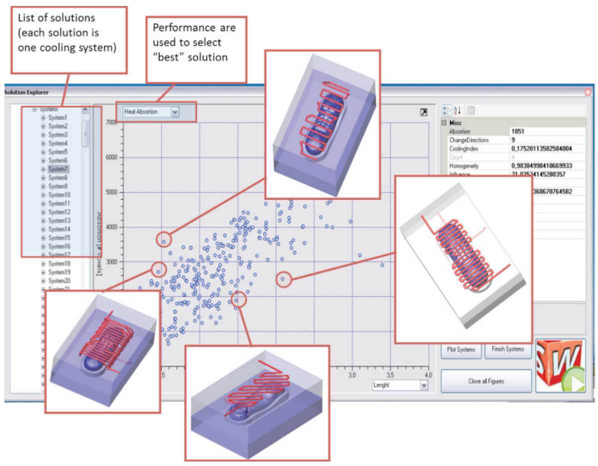

Fig. 4: User Interface of solution space exploration tool

6. Discussion

CAS enables the designer in engaging in a continuous design loop iteration that synchronizes the design problem space with the design solution space at a much more rapid pace than without it. Furthermore, the designers have control on the knowledge (e.g. equations, rules of thumb, constraints) used by CAS tool to generate solutions, as the system offers the possibility to add, remove and reformulate it by the user. As a result, CAS supports solution space generation, continuous design iteration and generation-knowledge control.

These three properties lie at the core of Lean Design's Set-Based Concurrent Engineering and Just In Time Decision Making. By generating sets of possible solutions, conflicting design criteria can be assessed concurrently and actively during the design phases. In the case that different stakeholders are responsible for the diversity of criteria, the tool streamlines the collaboratively set-up of requirements. Then, after the tool has generated feasible solutions, the stakeholders can compare different options and search for a solution that satisfies the criteria of each individual stakeholder. This “solution space exploration” process can lead to three different decision making options. One option is that the stakeholders determine that the requirements need to be adjusted. In this case, they can re-enter the requirements and have the tool generating a new set of feasible solutions. A second option is that each stakeholder has a different preferred design solution. In this case, each stakeholder can define its own range of preferences, and that solutions are selected at the intersections. A third option is that no solution satisfies all stakeholders concurrently. In this case, detailed information of the solutions performance indicators calculated by the tool can be used to negotiate and select one solution. Furthermore, as CAS enables the storage and operationalization of expert knowledge, it supports the maintainability of knowledge for future utilization.

References

[1] Ward, A. C., & Sobek Ii, D. K. (2014). Lean Product and Process Development (second.). Cambridge: Lean Enterprise Institute, Inc.

[2] Baines, T., Lightfoot, H., Williams, G. M., & Greenough, R. (2006). State-of-the-art in lean design engineering: a literature review on white collar lean. Proc. IMechE, 220(B), 1539–1547. doi:10.1243/09544054JEM613

[3] Sobek Ii, D. K., Ward, A. C., & Liker, J. K. (1999). Toyota’s principles of set-based concurrent engineering. MIT Sloan Management Review, 40(2), 67–83.

[4] Holman, R., Kaas, H., & Keeling, D. (2003). The future of product development. McKinsey Quarterly (2003), (3), 28–39. doi:10.1177/1534484308324984

[5] Al-Ashaab, A., Golob, M., Attia, U. M., Khan, M., Parsons, J., Andino, A., … Sopelana, A. (2013). The transformation of product development process into lean environment using set-based concurrent engineering: A case study from an aerospace industry. Concurrent Engineering, 21(4), 268–285. doi:10.1177/1063293X13495220

[6] Jauregui-Becker, J.M., From How Much To How Many: Complexity Management In Routine Design Automation, Ph.D. Thesis, Faculty Of Engineering technology, University Of Twente, 2010.

[7] Bolognini F., Jauregui Becker J. M., Schotborch W. O. An Investigation Into Limited Integration Of Computational Design Synthesis In Common Design Practice. Proceedings Of Design 2012, The 12th International Design Conference, Dubrovnik, Croatia.

[8] Chakrabarti, A., Shea, K., Stone, R., Cagan, J., Campbell, M, Vargas Hernandez, N., And Wood, C., Computer-Based Design Synthesis Research: An Overview, Journal Of Computing And Information Science In Engineering, 11, 2, 021003 – 021013, 2011.

[9] W.O. Schotborgh, E. C. M., F.J.A.M. van Houten, 2012., "A knowledge acquisition method to model parametric engineering design processes," International Journal of Computer Aided Engineering and Technology, 4(4).

[10] Menges, M., How to make injection molds, 1986: Hanser.

[11] Juan M. Jauregui-Becker, Guido Tosello, Fred J.A.M. Van Houten, Hans N. Hansen, Performance Evaluation Of A Software Engineering Tool For Automated Design Of Cooling Systems In Injection Moulding Procedia, Cirp 7 (2013) 270 – 275.

[12] Solidworks Coorporation, Api Documentation, 2007.