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AXIOMATIC DESIGN AS A CREATIVE INNOVATION TOOL APPLIED TO MOLD DESIGN

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ABSTRACT

Traditional design practices result, typically, in a poor design space exploitation, usually as a consequence of the short lead time and due to technical resources constraints. Moreover, given mostly time to market constraints, the main concern of product designers is to achieve an acceptable solution, instead of looking for the best one. This is the case of the design of mold tools for plastic injection. The injection mold is a high precision tool, responsible for the production of mostly plastic parts used everywhere. Its design is considered critically important to product quality and efficient processing, as well as determinant for the economics of the entire injection molding process. In this context, a fully integrated framework is proposed in order to support mold tools design. This framework encompasses Axiomatic Design (AD) as main methodology to support the Design stage. Thus, following AD guidelines, a few of conceptual solutions are generated by mapping the functional requirements previously identified onto the corresponding design parameters. Afterwards, the best conceptual solution is detailed and optimized with the aim of maximizing customer satisfaction. The developed framework was validated through an existing mold, where the results attained highlight the great potential of the proposed framework to achieve mold design improvements. In particularly, the value of mold solutions generated led to a global improvement on mold performance of 5%.

Keywords: Axiomatic Design, Design for Six Sigma, injection molding, mold design, product development.

1 INTRODUCTION

Currently, product development is assumed as the new frontier for achieving competitive advantage in today's rapidly changing business environments [Chan *et al.*, 2003; Low, 2003]. In fact, both managers and scholars increasingly understand the central role that product development plays in creating competitive advantage [Ferreira *et al.*, 2010]. This is especially true because decisions made during early design stages, designated as conceptual design stage, have the greatest impact over the total cost and quality of the system. Typically, these crucial decisions are mainly supported based on intuition, empiricism and the so-called handbook method. The consequence is a lot of failure-trial-fix loops and development costs dominated by failure recovery actions. Additionally, several iterations are typically necessary because of inherently conflicting trade-offs for which it is very difficult to find a balance. For these reasons, it is imperative to adopt new methods and tools allowing for a better exploitation of new and different alternatives for the design solutions considering its novelty and degree of response to customer's needs.

Regarding mold's tooling industry, this sector has been increasingly facing the pressure to reduce the time and cost of mold development, offer better accuracy and surface finish, provide flexibility to accommodate future design changes and meet the requirements of shorter production runs [Candal and Morales, 2005]. These mold tools must be custom designed and built, where, usually, no formal structural analysis is performed. Typically, the designer relies on his skill and intuition, and follows a set of general guidelines [Centimfe, 2003]. As a result, the conceived mold solution may be acceptable and not necessarily the best option [Tang *et al.*, 2006]. In fact, traditionally, the design practice involving mold design tends to quickly converge to a solution (corresponding to a point in the solution space), which is then modified until it meets customer's impositions. Therefore, subsequent iterations to refine the solution will generally occur after mold manufacturing and trial, where most of the design gaps will come up [Ferreira, 2002; Low and Lee, 2003]. Conscious of conceptual stage critical role regarding mold cost and performance, as well as time to market, this paper aims to provide a further contribution to the development of a global methodology to support mold design activities. For that purpose, Axiomatic Design (AD) will be adopted as main methodology to support the design stage of metallic mold tools for plastic parts injection [Ferreira *et al.*, 2009; Ferreira, 2012].

2 AXIOMATIC DESIGN METHODOLOGY

According to AD theory, the world of design is made up of four domains (Figure 1): the customer domain, the functional domain, the physical domain and the process domain [Suh, 1990]. The starting point of process design is the identification of Customers Attributes (CAs) in the customer domain. Then, these CAs must be translated to specific requirements designated as FRs, which are formalized in the functional domain. After that, considering that the objective of design is generated as a physical solution, characterized in terms of Design Parameters (DPs) (that meets FRs) the design must progress by interlinking these two domains (functional and physical) through zigzag approach. Finally, the last step involves interlinking the DPs with the Process Variables (PVs), which assures product production [Suh, 1990; Ferreira *et al.*, 2009].

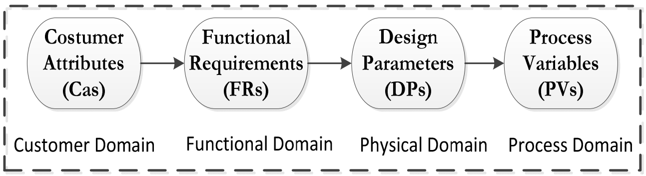


Figure 1. World of AD design: domains (adapted from [Suh, 1990; Yang and El-Haik, 2003])

A previous research work was done in order to identify mold's CAs and to translate them into FRs (first task of AD design process). Based on the gathered data [Ferreira *et al.*, 2008; Ferreira *et al.*, 2009], it was possible to identify these CAs, which are typically required by injection mold's customers when they ordered the mold (Figure 2).

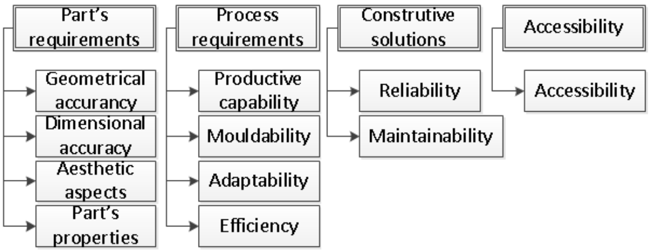


Figure 2. Typical CAs regarding injection mold design.

The next step in AD approach encompasses the translation of the previously identified CAs into FRs, which are the minimum set of functional requirements states in the functional domain (Table 1).

Table 1. Mapping CAs and FRs.

Customer attributes	Functional Requirements
Geometrical accuracy	Deflection
Dimensional accuracy	Shrinkage
Aesthetic aspects	Aesthetic defects (e.g. Sink marks)
Properties	Specific property (e.g. in cavity residual stress)
Productive capability	Cycle time
Moldability	Pressure drop
Adaptability	Mold's volume
Efficiency	Volume of material waste (i.e. scrap)
Maintainability	Mean Down Time (MDT)
Reliability of solutions	Mean Time Between Failure (MTBF)
Accessibility	Information content

After that, a few number of alternative molds solutions must be generated. This will be achieved by mapping these FRs into the respective DPs. Nevertheless, several architectural concepts can be developed to fulfill these FRs. In theory, the number of plausible solutions characterized by each DPs is unlimited depending only of the designer and the lead-time available for designing. Thus, AD support is considered essential to facilitate the physical structure generation [Yang and El-Haik, 2003] and to identify the potential system interactions (coupling) [Mohsen and Cekecek, 2000] helping the designer to think in different ways to answer the key functions, aiding to increase the degree of mold's innovation supported in a more rational approach.

3 DEVELOPED FRAMEWORK

According to Ulrich and Eppinger [2003], the concept Design stage must be divided into two consecutive parts: Concept Generation and Concept Screening. At the Concept Generation stage the objective is to generate as many as possible product concepts involving different design solutions. All solutions will be then evaluated and screened at the Concept Screening stage. The product concepts must be conceptually defined (i.e. high level system definition), which means that a roughly product design must be achieved through some technical decisions. As it was described, the proposed approach consists of using AD methodology to support the conceptual design stage, which is more focused on human creativity and intuition, aiming to guide the initial decisions in a more rational approach. For that purpose, the initial mold's design decisions will be defined by linking the previous identified FRs with DPs through zigzagging as established by AD. This FRs-DPs mapping will be developed for the upper levels in order to generate a few number of conceptual solutions for the mold. Afterwards, these solutions must be evaluated, in order to select the solution which has the most well ranked customer satisfaction level.

Currently, the search and generation of alternative methodologies for design of molds arises as an answer for the plastic industry to cope and compete with new market threats. The potential improvements on mold design only can be reached if the design process begins by broadly considering sets of possible mold solutions and, then, gradually narrowing the set of possibilities to converge to a final solution. This procedure, which helps to find more easily the best solution [Ulrich and Eppinger, 2003], can be achieved by a better exploration of the design space and by the resolution of system's trade-offs, early in the design. Moreover, since the design of an injection mold is a highly interactive process (i.e. involves substantial knowledge of multiple areas, such as mold design features, mold making processes, molding equipment and part design, all of which highly coupled to each other), a multidisciplinary view of injection mold must also be adopted [Ferreira *et al.*, 2010].

Based on that, an injection mold must be seen as a complex multidisciplinary system with some functional subsystems, such as the structural, impression, feeding, heat-transfer and ejection systems. The Feeding System (including the venting system) has the main function to channel the molten plastic material coming from the injection nozzle of the molding machine and distribute it into each cavity, through the runners and respective gate points. The venting subsystem must allow for gas release, because when the melt enters into the cavity the displaced air must have a means to escape.

The Heat-transfer System supplies the mold with a system of cooling channels, through which a coolant is pumped. Usually, its main function is to remove heat from the mold, so that - once filled - the part is sufficiently rigid to be demolded.

The Ejection System has the main function to knock out the injection molded parts, in order to release them from the mold. Typically, after the mold is opened, the hydraulic cylinder of the injection machine will actuate the ejection system to move forward, pushing the molded parts out. It is critical that the ejection system does not cause damage (marks) to completed parts.

The Structural System must allow the mold (tool) to be coupled into the injection machine and assure the overall assembly of its components. It is also necessary to guarantee the alignment and guiding of the mold.

Finally, the Impression system must give the required shape to the part. To do so, it is composed by the cavity, which is generally responsible for the external impression of the part, and by the core, which produces the internal impression. Additionally, in order to proceed with FRs-DPs mapping regarding mold design, it is important to define its main function. Considering that the main challenge of mold design is to design and produce a mold that is straightforward to manufacture, while providing uniform filling and cooling of plastic parts, as well as has to be strong enough to withstand millions of cyclic internal loads from injection pressures and external clamp pressures, in order to assure the target part's reproducibility [Ferreira *et al.*, 2010]. Based on that, Figure 3 presents the top design levels structure defined for the FRs and Figure 4 for the DPs.

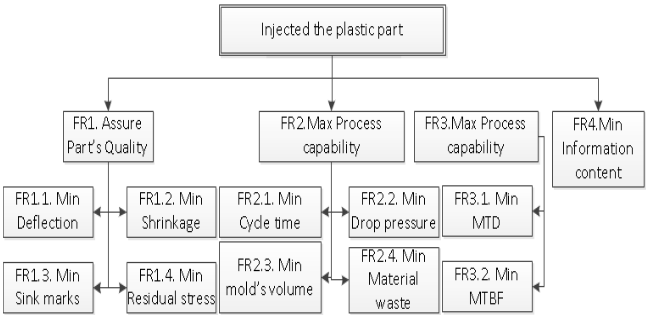


Figure 3. FRs defined for top design levels.

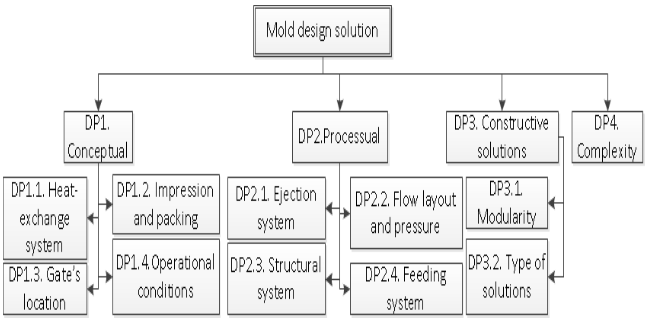


Figure 4. DPs defined for top design levels.

Based on the previous figures, it is possible to observe that, regarding the first two levels, the map between FRs and DPs has no special issues. However, this is not true for the third level, where some theoretical considerations were taken into account in its definition. A brief description of these considerations are:

i) DP1.1. - Deflection or warpage of an injected plastic part is a dimensional distortion that causes structural unfitness and aesthetic problems. This warpage is one of the critical quality issues for injection molded parts, because when the molded part does not satisfy a dimensional tolerance it is useless as a final product [Shen and Li, 2003]. According to some authors [Liu, 1996; Zheng *et al.*, 1999; Ozcelik and Erzurumlu, 2006; Gao and Wang, 2008], the warpage can be largely the result of thermally induced effects that arise during the mold cooling stage of the injection process. For that reason, the mold cooling system must be carefully set. Based on that, at the conceptual design stage of mold design this system was detailed in the following design variables (Table 2).

Table 2. Design variables regarding the heat-exchange design (DP 1.1.).

Design variable	Definition
n_turns	Number of turns of the cooling line in cavities

ii) DP1.2. - Controlling the part shrinkage is of paramount importance in mold design, particularly in applications requiring tight tolerances. The impression system design (i.e. cavity and core design) should take shrinkage into account, in order to conform to the part dimension. Therefore, these parameters were considered to be DP 1.2 (Table 3).

Table 3. Design variables regarding impression system design and packing conditions (DP 1.2.)

Design variable	Definition
position_parts	Position of each part relatively to the Partition Plane(PP)
partition_plane	Position of the PP

iii) DP1.3. - In general, the aesthetic quality of a molded part requires the absence of defects such as sink marks, bubbles, weld lines, flashing, etc., where one of the major problems is the presence of sink marks [Shen *et al.*, 2007; Shen *et al.*, 2007]. Several authors impute the quality of injected parts to the gate's location [Pandelidis and Zou, 1990; Lee and Kim, 1996], because it influences the way in which the plastic flows into the mold cavity. Therefore, sink marks were assumed to be mainly related with the gate's location. Accordingly, the design variables included in the model as determinant for the aesthetics defects formation are the number of gates and its position, as shown in Table 2.

Table 4. Design variables regarding the gate's location design (DP 1.3.).

Design variable	Definition
n_{Gates}	Number of gates per part
position_gates	Position of each gate relatively to the PP

iv) DP1.4. - The quality characteristics of the plastic injection molded products can be roughly divided into three kinds of properties: (1) the dimensional properties, (2) the surface properties and (3) the mechanical properties. Regarding mechanical properties, which involve, typically, the tensile strength and the impact strength of the plastic part, they are related with operational conditions of the injection process. Therefore, these operational conditions that encompass injection speed and temperature settings were assumed as DP 1.4 (Table 5).

Table 5. Design variables regarding operational conditions (DP 1.4.).

Design variable	Definition
Tmelt	Temperature of the melt
Tmould	Temperature of the mold
t_{inj}	Time of injection

Nevertheless, since mold's customers usually impose the plastic material and the injection machine parameters, these variables will be assumed as fixed following material's supplier recommendations.

v) DP2.1. - Cycle time can be defined as the sum of each injection stage time (e.g. Plasticizing, Injection, After-Filling or Packing, Cooling and Release [Rosato *et al.*, 2001]). Since only the release time (i.e. the time for mold opening, part ejection and closing mold) is not yet included, and because it is mainly function of the ejection system [Autodesk, 2010], the design of ejection system is assumed as DP2.1 (Table 6).

Table 6. Design variables regarding the ejection system design (DP 2.1.).

Design variable	Definition
$n_{Ejectors}$	Number of ejectors per part
position_ejectors	Position of ejectors in relation to the PP

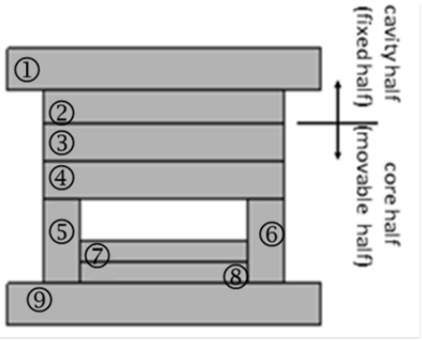
vi) DP2.2. – Higher moldability occurs when the pressure drop per unit length is constant along the flow path. This pressure drop must be minimized since it reduces the injection pressure needed to inject the melt. Moreover, it is important to note that by using lower injection pressure, power is saved and the wear and tear on machines is minimized, consequently enlarging the mould's life. Based on that, Moldability can be described by the flow path length defined by the feeding layout (Table 7).

Table 7. Design variables regarding the flow path (DP 2.2.).

Design variable	Definition
type_layout	Type of feeding layout

Note that, there are three possible feeding configurations or layouts for cold runners, namely, Symmetrical (or in series configuration), Circular and Hybrid (i.e. that combines both circular and symmetrical layouts). A symmetrical layout can mostly compactly deliver the melt to many in-line cavities through a single primary runner, with many subsequent secondary runners leading to individual cavities. Since the secondary runners branch off at different locations down the length of the primary runner, the flow rate will be different for each cavity (lower for the cavities located further away from the sprue). This disadvantage can be overcome by assuming different diameters for each cavity, which can be difficult to do in practice. An alternative solution can be the branching of the feed system in multiple locations (multiple branching). Regarding circular layouts, they naturally assure a balanced flow rate and melt pressure, with a moderate amount of runner volume. However, this balance is somewhat limited to the base of the sprue. Nevertheless, this can also be overcome by multiple branching. Note that multiple branching has limits, since a branched layout consumes significantly more material while it also imposes a higher pressure drop between the sprue and the cavities.

vii) Regarding the FR2.3. (Mold's size), and because the structural system design is the one that contributes the most for the size of the mold, it was defined as DP2.3. Considering a 2-plate mold (Figure 5), the design of structural system is assumed as DP 2.3. (Table 8).



1	Injection clamping plate or top clamping plate
2	Cavity retainer plate or plate A
3	Core plate or plate B
4	Core retainer plate
5, 6	Spacer Block
7	Ejector pin plate
8	Ejector pin retainer plate
9	Ejection clamping plate or bottom clamping plate

Figure 5: Typical structure for a 2-plates mold type.

Table 8. Design variables regarding the structural system design (DP 2.3.).

Design variable	Definition
mold_material	Mold's material
cavity_material	Material for cavity's inserts

viii) About FR2.4., Volume of scrap, and considering only cold runner molds, it is possible to verify that this FR depends upon the volume of the feeding system. Thus, the correspondent DP is the feeding system design. The outcome of the deploying of this system into the design variables that must be considered at the design stage is the type of runners cross-section (Table 9).

Table 9. Design variables regarding the feeding system (DP 2.2.).

Design variable	Definition
type_runner	Type of runners cross-section

Regarding the type of possible geometries for the runners' cross-section, there are the Full-Round (FuR), Trapezoidal (T), Rectangular (R) and Half-Round (HR). A detailed description of the advantages and disadvantages of each type can be found in [28-32]. Based on their characteristics, the FuR circular runners were adopted, which is extremely common in mold designs, because they render uniform shear rates and shear stresses around the perimeter of the cross-section.

ix) For the remaining FRs, namely FR3.1. (Minimize MDT) and FR3.2. (Maximize MTBF), they are mapped with DP3.1. (Standardization/Modularity) and with DP3.2. (Type of constructive solutions), respectively. In relation to the FR4. (Maximize information content of mold), it is mapped to DP4 (Minimize mold's complexity), since the objective is to design the simplest mold solution. Nevertheless, at this stage these requirements are not included in the model, for the reason that they are not previously explored in the literature as design parameters of injection molds.

4 CASE STUDY: KEY HOLDERS MOULD

In order to test the proposed approach, an existing injection mold was used as baseline in order to compare mold solution obtained through traditional procedures and mold solutions achieved by the proposed approach. Figure 6 presents the existing mold, which is used to produce four key holders in each cycle.

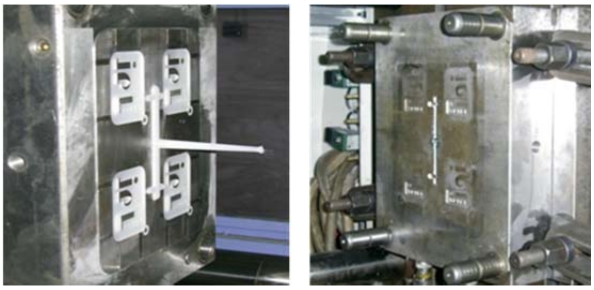


Figure 6. A view of the existing mold for key holders.

The selected plastic part's material is Moplen HP 500N, produced by Basell Polyolefins. The existing mold is a 2-plate mold, with nine plates, where a DME standard structure made of 1.1730 steel was adopted. Regarding the injection molding machine, a EuroInj was employed, with a maximum locking force of 7.84E5N and a screw diameter of 32mm.

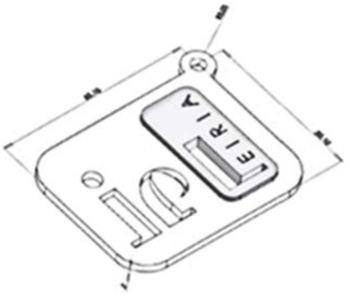


Figure 7. Geometric data regarding the injected key holder.

As mentioned before, the main objective of Design stage is to conceive rough design layouts, where each concept is generated through the combination of each design variable alternatives characterized by each DPs. These design variables, previously obtained through FRs-DPs mapping, are summarized in Table 10. Then, by assigning different values to each conceptual variable, a number of different conceptual solutions for the mold can be accomplished.

Table 10. Design variables considered in the design stage.

Mold system	Design variable	Value
Heat-exchange	*n_turns*	Integer (2, 4)
Impression	*position_parts*	Geometrical (I, II)
Feeding	*position_gates*	Geometrical (A, B)
Ejection	*position_ejectors*	Integer (2,4)
	nEjectors	(Circular, Symmetrical)

Based on the design variables presented in Table 10, a few number of conceptual solutions must be generated combining the alternative options proposed by the mold designer that were established according to industrial practical guidelines [Centimfe, 2003]. Figure 8 exemplifies the two possible alternatives for the number of turns of each cooling line. Two different positions of the parts, relatively to the PP, are exemplified in Figure 9. Figure 10 shows different positions for each gate, relatively to the PP, for the same parts positioning. Figure 11 exemplifies the two alternatives for the type of feeding layout, also considering the same parts positioning. Finally, Figure 12 shows the two possible alternatives for the number of ejector pins, per part. These figures are shown to highlight the geometrical complexity of these conceptual solutions. Afterwards, these solutions will be evaluated and compared, in order to select the conceptual solution that has the highest rank customer satisfaction level.

In this study, some variables were considered fixed, mostly due to the characteristics of the existing mold, in order to enable a better comparison between the results attained by the proposed approach and the reference. The variables that were assumed as fixed are presented in Table 11, which shows also the fixed value considered.

Table 11. Fixed variables at the Design stage.

Symbol	Fixed value
partition_plane	Geometrical (Baseline)
type_ejectors	Full-Round (FuR)
mould_material	1.1730
cavity_material	1.1730

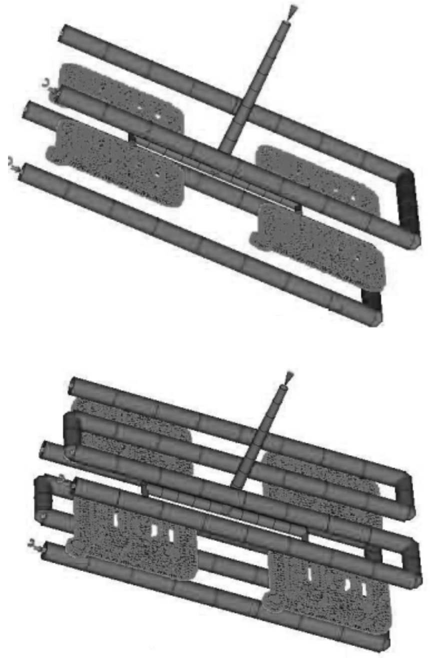


Figure 8. The two possible alternatives for *n_turns*: two turns (left) or four turns (right).

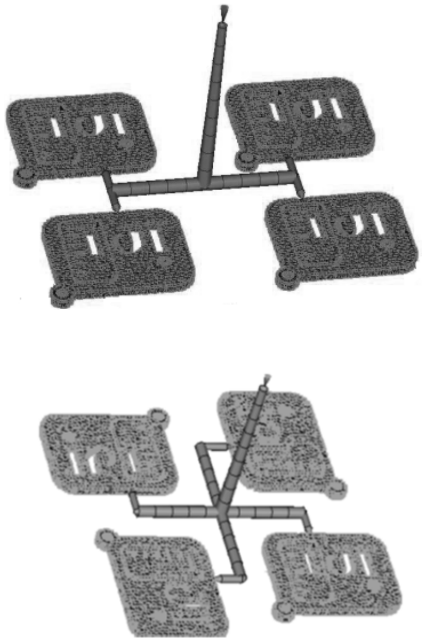


Figure 9. The two possible alternatives for *position_parts*: Position I (left) or Position II (right).

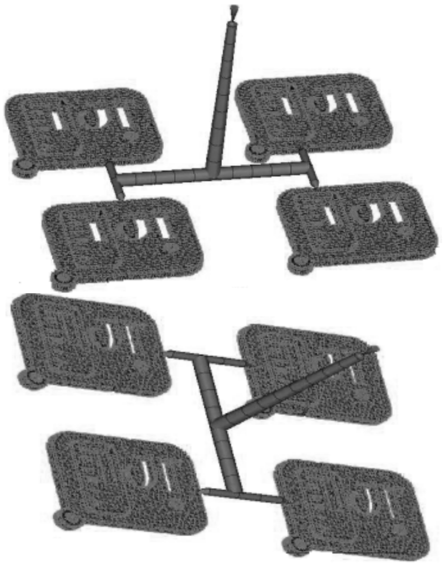


Figure 10. The two possible alternatives for *position_gates*: Position A (left) or Position B (right).

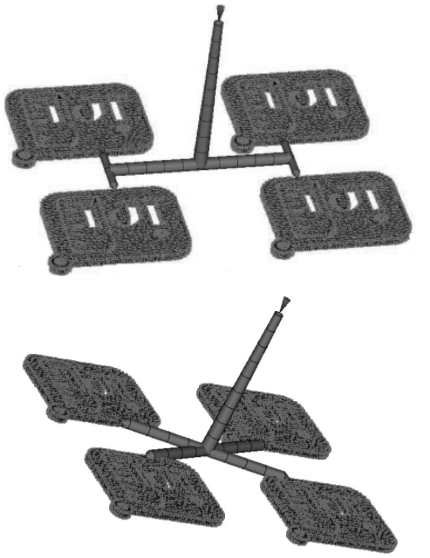


Figure 11. The two possible alternatives for *type_layout:* Symmetrical (left) or Circular (right).

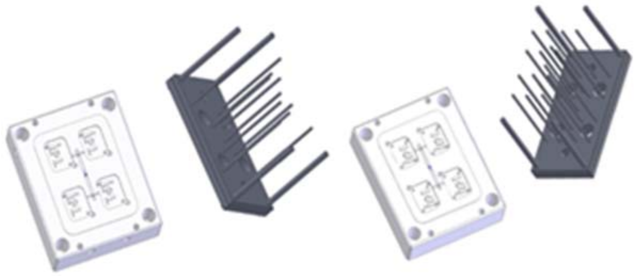


Figure 12. The two possible alternatives for $n_{Ejectors}$: two pins per part (left) or four pins per part (right).

Due to the number and type of design variables considered at this stage, a total of 32 conceptual solutions were evaluated. For that purpose, it was requested to this mold customer to compare each previous identified CAs (see Figure 2), two at a time, using a 1-9 scale with three levels. Hence, through Analytical Hierarchical Process (technique that is widely used for addressing multi-criteria decision-making problems [Chuang, 2001]), each attribute was ranked according to its relative importance to the customer, aiming to build a weighted objective function. The results achieved can be observed in Table 12.

Table 12. Relative priority of each CA regarding key holders mold.

CAs	FRs	Relative weights
Geometrical accuracy	Deflection	12.2%
Dimensional accuracy	Shrinkage	12.2%
Aesthetic aspects	Sink marks (*Sink*)	22.9%
Properties	Residual stress (Stress)	2.0%
Productive capability	Cycle time (*tCycle*)	2.8%
Moldability	Pressure	16.3%
Adaptability	Mold's volume (*Vmould)*	1.8%
Efficiency	Waste of material	5.3%
Maintainability	MDT	5.8%
Reliability of solutions	MTFB	5.0%
Accessibility	Information	13.7%

Based on that, it is possible to observe that the most important attributes are the aesthetic aspects and moldability. This ranking is a little bit different from industrial practice, where the most important attributes are usually also aesthetics aspects, but where, typically, cycle time, geometrical and dimensional accuracy have at least a similar importance. However, since the selected mold is not a commercial application, the attained values are coherent. Based upon these values, it was possible to express the Quality of Mold (QM) as:

$$\begin{aligned} QM = [(&0.122\mathrm{Deflection} + 0.122\mathrm{Shrinkage} + 0.229\mathrm{Sink} \\ &+ 0.02\mathrm{Stress}) + (0.28\mathrm{tCycle} \\ &+ 0.163\mathrm{Pressure} + 0.018Vmould \\ &+ 0.053Waste) + 0.058\mathrm{MDT} \\ &+ 0.05\mathrm{MTBF} + 0.137\mathrm{Information}] \end{aligned} \tag{1}$$

Figure 13 presents the most well ranked conceptual solution (i.e. that have the highest QM value), which has two turns of cooling channels, position II of the parts on the PP, symmetrical feeding layout and gates positioned on point B. Regarding the number of ejectors, based on the results achieved, it was observed that it has no effect over QMD value.

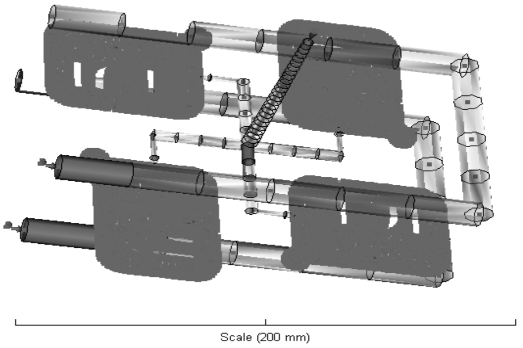


Figure 13. Most well ranked conceptual solution.

Afterwards, this conceptual design solution will be detailed and optimized through a platform, developed with the aim of maximizing customer satisfaction. To that end, Eq. (1) will be used as single objective function defined as a weighted function of the previously determined FRs. For that purpose, it was built a platform where thermal, rheological and structural analyses are undertaken by high-fidelity codes, namely Autodesk Moldflow® Insight 2010 code [Autodesk, 2010] and ABAQUS version 6.10-1 [Simulia, 2011]. An overseeing code, ModeFRONTIER version 4.4.1 [Esteco, 2011] was responsible for managing the connections between the codes, launching the simulations, accessing the outputs and changing the input data according to the pre-defined mathematical exploitation and optimization schemes [Ferreira, 2012]. A comparison between the most well ranked conceptual solution optimized (Figure 14) and the baseline is presented in Table 13.

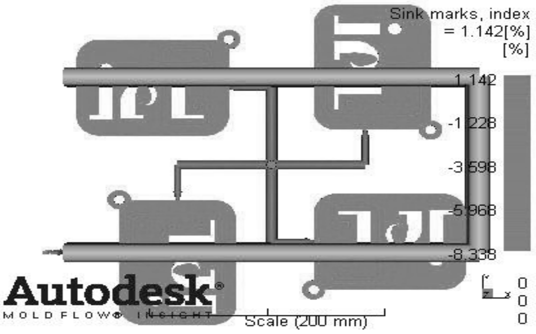


Figure 14. The optimized most well ranked conceptual solution.

It is possible to verify that major improvements were achieved in all the objectives, expect Pressure drop and Cycle time. As shown in Table 14 the selected solution presents a reduction on Sink index of 26%, on Waste of 25.1%, on mold's Volume of 9.1%, on Deflection of 11.4%, on Cost of 7.6%, and a drop on Shrinkage of about 0.8%. On the contrary, the achieved solution has a very important increase in Pressure drop (31%) and in Cycle time (6.3%). In average, the well ranked solution allows for an improvement on performance of about 5%. This enhancement can result in an increase of quality of mold design in almost 4%.

Table 13. Selected conceptual solution and baseline solution.

	Baseline	**Selected solution**
$n_{Ejectors}$	4	4
n_turns	2	2
position_gates	A	B
position-parts	I	II
type_layout	S	S

Table 14. Comparison between the performance of the baseline and the well-ranked solution.

	Baseline	**Well-ranked**	**Impact**
Shrinkage (%)	12.24	12.14	-0.8%
Sink	1.54	1.14	-26.0%
Vmould (m^3)	1.98E-02	1.80E-02	-9.1%
Deflection (mm)	8.13E-04	7.20E-04	-11.4%
Pressure (MPa)	11.14	14.59	31.0%
Stress (MPa)	2.018E+04	2.02E+04	0.0%
tCycle (s)	39.44	41.933	6.3%
Waste (mm^3)	5.18E+03	3.88E+03	-25.1%
Cost (€)	1133.1	1225.9	-7.6%
Global improvement (in average)			**4.7%**
Quality of Mold			**3.7%**

Thus, it is possible to verify that the selected solution presents a global improvement of almost 5% on its performance, and leads to an increase of nearly 4% over quality of mold design

5 CONCLUSION

The main objective of this paper was to describe a new approach, which adopts the Axiomatic Design (AD) methodology to support the design stage of molds tools for plastic injection. In this sense, the framework proposes to carry out the conceptual design through AD approach aiming to map FRs with the corresponding DPs. It is possible to conclude that AD is helpful to facilitate the physical structure generation, as well as to identify potential system interactions (i.e. couplings). Through an existing mold comparison, it has been demonstrated that AD can help to generate more adequate solutions regarding its key functions. It also helps to think in different ways to answer the key functions, aiding to increase the degree of mold's innovation. It is important to note that at the top level of product design, theoretically all design solutions are possible. In fact, early in the design process, there is a complete freedom for decision making, since there are no limits caused by previous decisions. On the other hand, knowledge about the implications on product performance of these design decisions is scarce. Thus, it becomes even more important to conceive and evaluate different conceptual solutions, in order to understand and identify the critical aspects of the design and its implications on product's performance.

For that reason, this design proposal surpasses the traditional design practices that lead, typically, in a poor design space exploitation (mostly due to time constraints, where the main concern is to achieve an acceptable mold solution instead of looking for the best one). In fact, using an existing mold it was demonstrated that with the proposed approach, it was possible to achieve a global improvement on performance of almost 5% resulting in an increase in quality of mold design of about 4%. Therefore, it is our belief that the proposed approach will help designers to achieve a more efficient design of mold tools, as a way to face the current market challenges.

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