Intelligent Support to Specific Design Aspects

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Abstract: - Due to increased rivalry on the market, some specific design aspects like the use of modern plastics materials, ergonomics and aesthetics are becoming more important and are not kept in the background any more in correlation with functionality and economic aspect of the product. Design engineer faces many dilemmas while designing new products as a single person is not able to possess a wide spectrum of knowledge needed for optimal design solutions. At this point designer have to rely on his or her experience and on the knowledge of the expert team involved in the project. The fundamental purpose of the research presented in this paper is to make the product development process less experience dependent. The main goal of thematically oriented research is to develop intelligent advisory system with integrated modules for some specific design aspects.

Key-Words: - product development, ergonomics, aesthetics, plastics, knowledge based engineering, intelligent systems

1 Introduction

The use of computers in modern design process is almost inevitable. Computer Aided Design (CAD) is extensively applied in every company that wants to stay competitive on the market. Yet, the existing CAD systems concentrate rather too much on graphic presentation of the design, but have the limitations in providing design information and advice.

Even though CAD systems concentrate mainly on the modelling of designs, the range of properties that are well represented in CAD is quite limited. Only the geometric form and dimensions are covered satisfactory, whereas the other properties like tolerances, material, surface condition, etc. are generally covered by annotation of a drawing, or by attaching attributes to a three–dimensional model. Moreover, even the geometric aspects of a design could be modelled much more in a way that designers think of them, for example in terms of manufacturing features like a drilled and taped hole. In fact, a route that is currently being explored in CAD research is to represent components in terms of higher–level entities, called "features", which do have some engineering meaning.

Design projects normally originate in form of problem statement provided to the designer by someone else – the client or the company management. These problem statements set a *goal*, some *constraints* within which the goal must be archived, and some *criteria* by which a successful solution might be recognised. It is usually possible to improve the initial definition of the problem.

Yet, many design constraints and criteria still remain unknown and the existing CAD approaches are not able to help designer in dealing with uncertainty and inconsistencies. Thus, the quality of design solution depends mostly on the designer's skill and experience.

Designers face many dilemmas linked with various aspects of the product. Thus, compromises have to be considered at every design step. In order to create as optimal compromises as possible, designers have to possess wide range of knowledge and be aware of all influential parameters, or alternatively a team of experts in various fields has to collaborate in development process [1].

Many successful companies deal with development of new products every day. Each of these products is being exposed to the competitive struggle on the market, where success can be expected only for universally optimal design solutions. Thus, some development aspects, such as manufacturing or aesthetic and ergonomic value that have been in the past mainly subordinated to functionality and economic efficiency of the product, are becoming increasingly important.

2 Intelligent systems in design

The Artificial Intelligence (AI) applications to design are generally concerned with studying how designers apply human intelligence to design, and with trying to make computer aids to design more knowledgeable. These applications are concentrated mainly into representation of heuristic knowledge that is less easy to express by using traditional mathematical approaches.

The part of AI that is particularly concerned with the development of such representations are known as expert systems, or more generally knowledge–based systems, often also intelligent computer systems [2].

Preliminary condition for intelligent system functionality is existence of the knowledge base, which is foundation for the Knowledge Based Engineering (KBE). KBE is an engineering method in which knowledge about the product, e.g. techniques used to design, analyse, and manufacture the product, are stored in the knowledge base or product/process model. The model represents engineering intent behind geometric design. It contains the attributes of the product such as material type, functional constraints, geometry etc.

Although AI technology is still subject of extensive research and development, many successful AI applications in real–life domains already proved the usefulness of these technologies when dealing with nondeterministic problems that cannot be treated adequately by using conventional approaches, unless the user is possessed of special skills and experience. Engineering design process is certainly one of the domains that very much fit into this scope.

It is becoming increasingly evident that adding the intelligence to the existing computer aids, such as CAD systems, leads to significant improvements of the effectiveness and reliability in performing various engineering tasks, including design. Actually, AI applications to design are reality and subject of intensive development and implementations. Proceedings of the international scientific conferences “AI in Design”, edited by J. S. Gero, constitute a good collection of papers related to this area [3].

Intelligent computer support to design may be classified into four broad groups, as follows:

(1) intelligent consultative systems for guiding inexperienced users,
(2) intelligent systems for ‘automated’ design of particular type of products,
(3) intelligent analytical aids,
(4) intelligent systems for product design optimisation considering specific design, manufacturing or application aspects.

In present, the extensive research in our laboratory is focused on development of the consultative intelligent advisory system for supporting a special, very interesting and important area of design application, i.e. development of plastics products with the appropriate ergonomic and aesthetic value. Three intelligent modules, which are going to be presented in this paper belong in the last group listed above (4).

3 Specific design aspects

Customer needs and product specifications are the basic guidelines in the concept phase of product development. However, during the later design activities, development teams often have difficulty to link specifications and needs to specific design issues they face. For this reason, many design engineers address specific design aspects by using so called "*design for X*" (DFX) methodologies, where X may correspond to one of many quality criteria, from more general, such as reliability, appropriateness for assembly, robustness, and maintainability, to more specific, like environmental impact, ergonomic and aesthetic value, etc. [4].

The most common of these methodologies is design for manufacturing (DFM), which is of universal importance, because it directly addresses manufacturing process and its costs. Effective DFM practice leads to low manufacturing costs without sacrificing product quality. DFM is one of the most integrative practices involved in product development. All members of the development team as well as outside experts need to contribute their part of expertise. However, the other specific design issues are also of crucial importance.

The upper part of the Figure 1 shows product development process, following four phases of design: task clarification, conceptual design, embodiment design and detail design. The designer is moving through the phases according to his or her own and expert team’s knowledge. As the alternative to the extensive expert team, which is often not on disposal, we decided to develop a supplement to the existing computer-aided design tools in form of the intelligent advisory system for supporting specific design aspects. It is anticipated the proposed system to comprise several intelligent modules, each based on the knowledge base for specific design aspect. Within project presented here, it is planned to concentrate mainly on development of three intelligent modules:

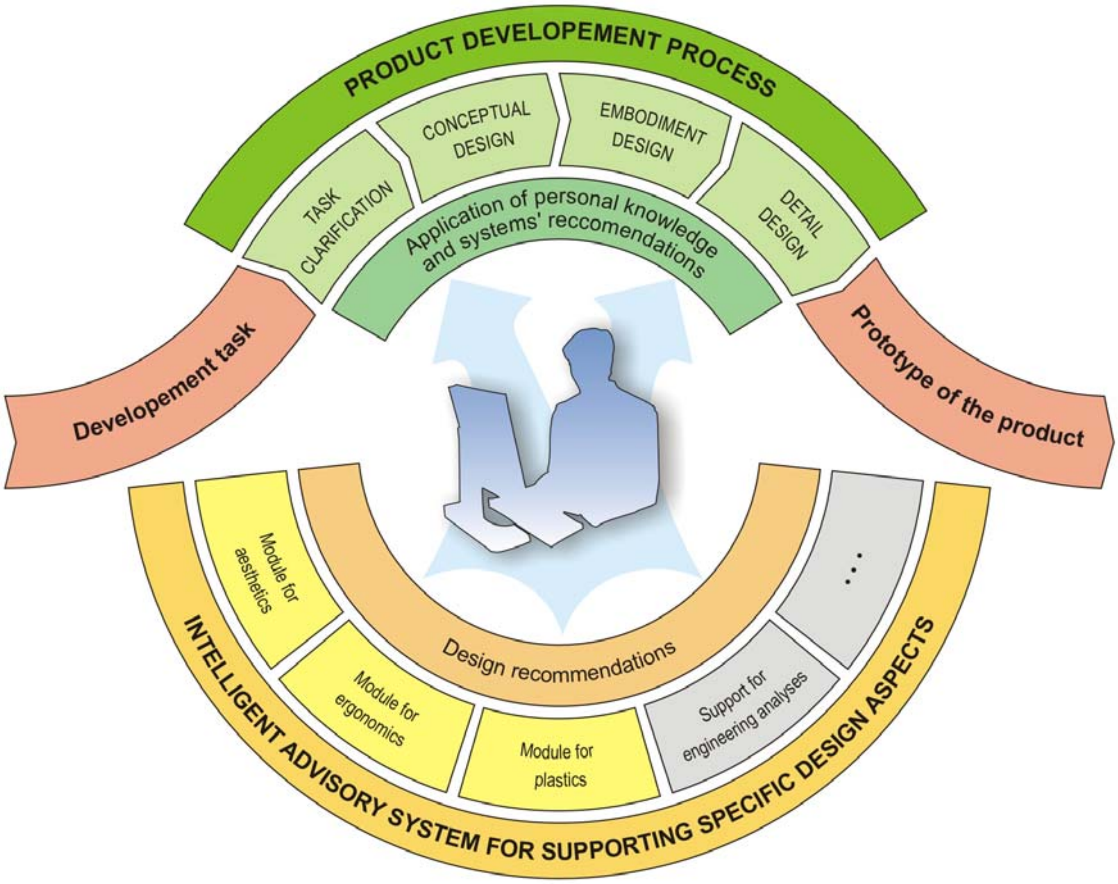

Fig. 1. Product development process supported with intelligent advisory system.

(1) module for design of plastics products,
(2) module for ergonomic design, and
(3) module for aesthetic product design.

The last two intelligent modules are closely linked, as the aesthetics and ergonomics of the product are always in relation, either to supplement each other or sometimes in certain extent also to exclude one another.

The lower part of the Figure 1 shows the idea of the proposed intelligent system, also presenting the intelligent module for supporting engineering analyses, which was already developed in our research group, and gave promising positive results. In addition, there is a possibility for new modules to be developed in the future.

Above all, the main purpose of the proposed intelligent modules is to support inexperienced designer by providing a qualified stream of advices in terms of design recommendations and guidelines related to specific design aspects. Consequentially, the designer will be able to find optimal design solutions easier and faster.

4 Plastics products development process

4.1 Scientific background

In present time, only the most innovative enterprises, which are investing in development and are keeping up with their competition with the intention to take the leading position on the market, can be successful. In the past, the designers were deciding mostly upon well-known tested materials like metals, wood and ceramics. Today this kind of materials can be replaced with others, which could be more suitable for the certain type of product. Plastics are one of those alternative materials, as they can offer optimal characteristics for noticeable lower costs. Due to the assortment of materials available on the market, the expert working team should be numerous, while planning the new product. Consequentially, the designer is forced to rely upon knowledge and experience of the working partners.

The major problems of plastics product development process can be summarised in the two groups:

(1) Due to insufficient understanding of plastics materials (knowledge spectrum about specific characteristics is far too extensive to be mastered by a single person/designer), tradition at using other favourable tested materials, and quantity of plastics on the market, these materials are not applied adequately in engineering practice.
(2) Information about plastics, their properties, related machining processes and matching design recommendations are not properly collected and organised for engineering use.

However, to consider the world without plastics is today almost too inconvincible to imagine. Yet, the majority of product designers are still better trained in the use of metals, and non-plastics, for product design. Their selection of the material best suited to the purpose of the product is based on their experience, creativity and product performance requirements.

4.2 State-of-the-art

There are many design issues to consider for good product development. Determination of the material to be selected for an application is certainly one of these issues. Today product designers have a vast menu of something over 120 thousands materials at their disposal to select from. Most of these materials belong to one of various plastics generic families. Each generic family of plastics is unique and fulfils specific product and user applications.

Plastics can replace existing materials such as metals, wood, and ceramics, to create new products. Moreover, basic plastics properties can be enhanced when they are mixed or alloyed with other plastics, fillers, reinforcements and other modifiers including colour to develop more unique and distinctive materials for special products.

Plastics today fulfil and satisfy the most rigorous customer requirements at reduced costs. However, plastics may not always work for all products, although there are now very few applications, except in high heat, high sustained load, or severe chemical situations, where plastic material is not suitable.

Design of modern plastics product requires quite extensive list of basic steps and procedures to perform in order to develop competitive products for today's world-class markets [5]. This process is too complicated to be successfully completed by a single designer. There are just too many variables in terms of different design solutions, materials, moulding and processing procedures, for a single plastic expert to be able to make all the correct decisions. Thus, the design process requires a team approach utilising design specialists along with material, tooling, equipment, and services consultants. Moreover, designing parts for today's polymers requires a more involved and upfront engineering approach than ever before. In this context, computer support to the process of designing plastics products is essential.

There are quite many AI applications reported in this particular field of design. More than ten years ago, Rapra Technology Ltd. [6] has claimed to launch the first ever knowledge based system for the plastic industry. Most of the later AI applications are addressing separate parts of design process, i.e. the selection of specific materials, such as ceramic [7], or the use of special manufacturing and corresponding tooling processes, where injection moulding is far the most popular [8,9]. However, there has not been any reported attempt aimed to develop such intelligent system that would be applied to support the whole process of designing plastics products with some vital advices and practical design recommendations. Thus, our research proposal represents a novel approach in this field.

4.3 KBE and DFX procedures

Many factors influence the selection of the material for the specific part. Beside basic demands and needs that are required for the application, the additional factors include material supplier recommendations, past experience, the choice of the competition, etc. However, the choice of material cannot be made independently of the choice of process by which the material is to be formed, joined, finished and otherwise treated. The influence of the material on the environment is also becoming increasingly important.

Designing parts for today's polymers requires a more involved and upfront engineering approach than ever before. This is particularly true for components that are combined into more complex parts, especially when the challenge is to reduce or eliminate the use of fasteners required to assemble them. In this context, DFX principles play a special important role in design of plastics products. Although DFX methodologies are of special importance for plastics product development, designers can expect very limited support in facing the challenge to design plastic parts and components of maximised quality at minimised costs.

It is evident that expert support in decision-making process is essential for almost every designer to perform design of plastics products successfully and efficiently.

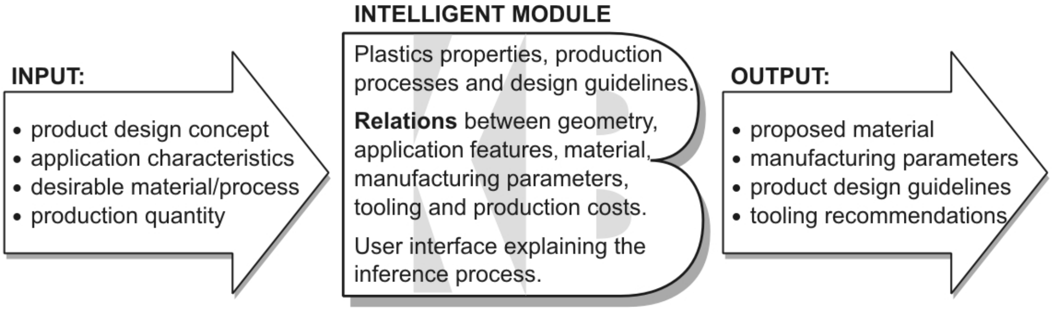

Fig. 2. Knowledge-based design of plastics products.

Thus, we decided to develop an intelligent advisory system to support this important design issue.

Figure 2 shows the expected data flow, the content of the knowledge base and the most important input/output data for the proposed intelligent support to design of plastics products. The main objective of the proposed system is a consultancy with the designer in order to find the most appropriate material for the product application, and in continuation, related manufacturing parameters, product design guidelines and tooling recommendations, that will ensure high quality standards at low production costs.

Figure 3 presents the comparison between conventional approach of plastics product design and design process supported with the intelligent advisory system. The designer receives the requests, wishes, conditions and due dates either from the management or direct from the customer. The responsibility of designer is to design the model, tool or finished product by carrying out the whole development process.

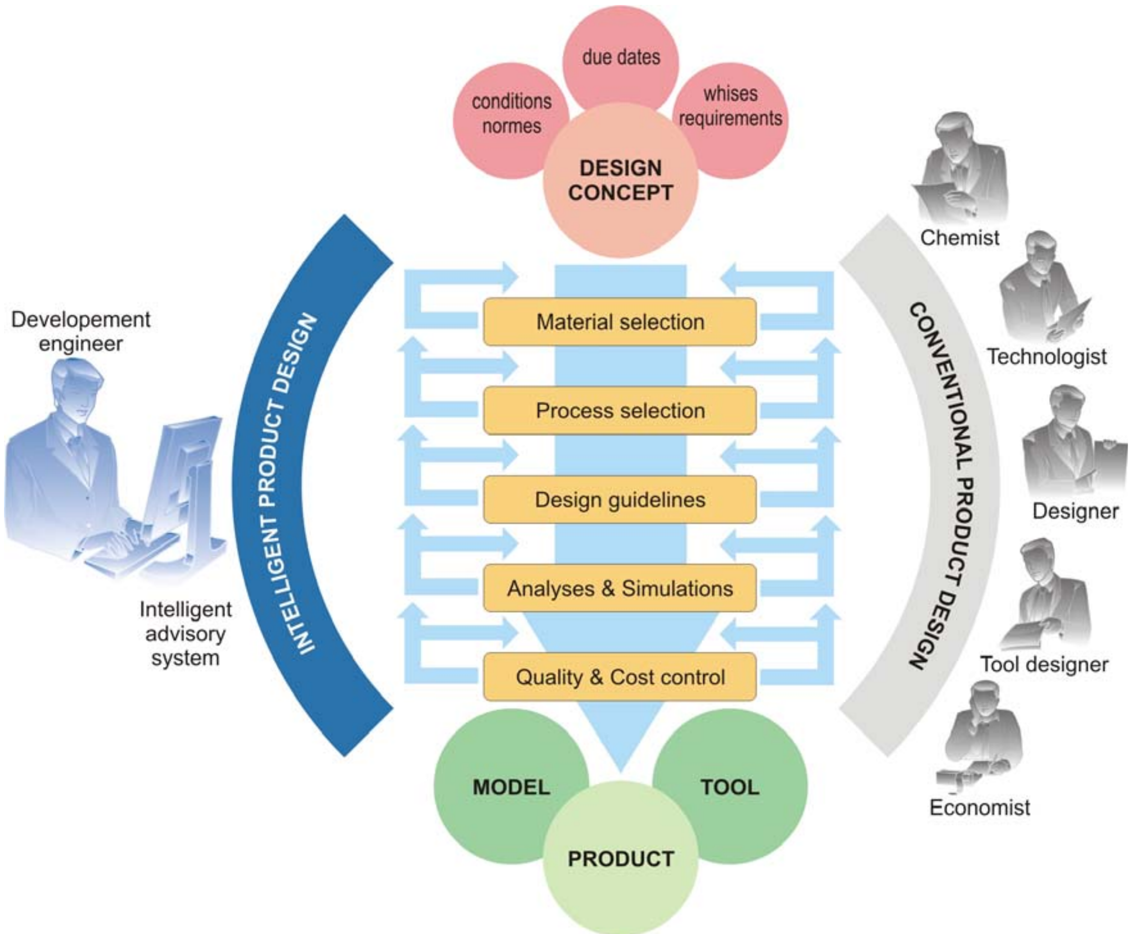

Fig. 3. Design process supported with intelligent advisory system vs. conventional approach.

As already mentioned, one person/designer is not able to absorb the existent spectrum of knowledge to take the optimal decisions. Thus, designer should consult with experts like technologist, chemist, tool designer and economist, who are able to deliver their expert knowledge. Together they can perform optimal solution. Alternatively to the expert team, some tasks like choosing the material and process, presenting the design guidelines, performing the analyses and monitoring the quality and costs, can be supported by applying the intelligent advisory system proposed here.

In present practice, design process is sometimes still successive. The customer provides the designer with input data where the requests often predominates technical criteria. For this reason, the designers and technologist are often handicapped when trying to enhance the quality of the product or a process. In this case, the need for intelligent computer support is essential. It is obvious that computer support will enable designers to make the right decisions and judgements more effective and less experience-dependent. The group of experts working on one project will be contracted and the customer will received the product in much shorter time. With suchlike computer tool, the business goal “maximum quality at minimal costs” will become achievable.

5 Design for ergonomics and aesthetics

5.1 Scientific background

Along with the material selection, other design parameters are also very important. Particularly for consumer products, aesthetics and ergonomics need to be considered. In the past, these domains have been often predominated with functionality and economic efficiency of the product. Today, aesthetics and ergonomics are becoming indispensable. When determining aesthetic value of the new product (styling phase), designers have to consider ergonomics too in order to create optimal design. Thus, compromises have to be made at every design step.

In order to create optimal design solutions designer has to poses a wide range of knowledge, including knowledge related to aesthetics and ergonomics, or an expert team has to collaborate in development process. As an alternative to the expert team, the intelligent advisory system is proposed to be applied to provide expert support to designer in the product development process.

5.2 State-of-the-art

5.2.1 Ergonomic design

Computer support to ergonomic design has been focused toward integrated tools that enable the use of ergonomic data from various sources when performing ergonomic analysis of the product or working process [10].

Two different approaches have been used for developing these software tools [11]. One approach is oriented into development of so-called stand-alone ergonomic CAD software with ergonomic assessment capabilities and built-in usually simplified module for three-dimensional modelling. The alternative approach is leading to development of the so-called compatible ergonomic software, which is based on special modules that are applied to perform ergonomic analyses within commercially available CAD systems that are primarily used for three-dimensional modelling and at the same time provide the integral user interface. Both types of computer tools mentioned can be classified as conventional software that enables various ergonomic analyses and simulations [12]. By applying these tools, the designer can evaluate the ergonomic value of the candidate design. However, if design needs to be changed to improve the ergonomics of the product, designer cannot expect to get a qualified advice how to do it. Relevant literature does not report any serious attempts to provide such advice by applying AI methods to support this important decision making process.

5.2.2 Aesthetic design

The aesthetic design phase, also called styling, still represents a serious bottleneck in the CAD process chain. Designers do not have at their disposal any serious commercial computer aided aesthetic software and have to trust to their aesthetic abilities and feeling in order to perform product design of complex-shaped products like car hoods, toys, etc.

It is very hard to define a procedure that would assure acceptable results of the aesthetic design process. Two European projects: FIORES and FIORES-II (FIORES - Formalisation and Integration of an Optimized Reverse Engineering Styling) aim at building innovative CAD tools that adhere to the creative user mentality and at improving the cooperation between the main players involved in the product development process, by identifying shape properties directly affecting the aesthetic character, and by providing modelling tools for their evaluation and modification [13]. Again, there is no clear evidence about any successful AI applications in this domain.

5.3 KBE and DFX procedures

Function and profit should have been ensured in the past and often had to have the dominance over some other design aspects like ergonomics and aesthetic. Today, aesthetic and ergonomic values are important as early as in the styling phase and designer has to consider them in order to create optimal design for a new product. The knowledge needed for product design optimisation is too extensive for one design engineer. Thus, the expert support is required.

As an alternative to the expert team, constituted of aesthetics and ergonomics experts, two intelligent modules of intelligent advisory system for supporting specific design aspects in field of aesthetic and ergonomics are proposed. The proposed modules are:

(1) intelligent module for ergonomic design, and

(2) intelligent module for aesthetic design

The system concept, based on independent modules, will enable the use of each module individually. On the other hand, when both modules will be applied simultaneously, the system needs to be able to propose optimal combination of the proposals.

Figure 4 shows the inference procedure for knowledge-based support to the ergonomic and aesthetic design, including the harmonisation between ergonomic and aesthetic recommendations.

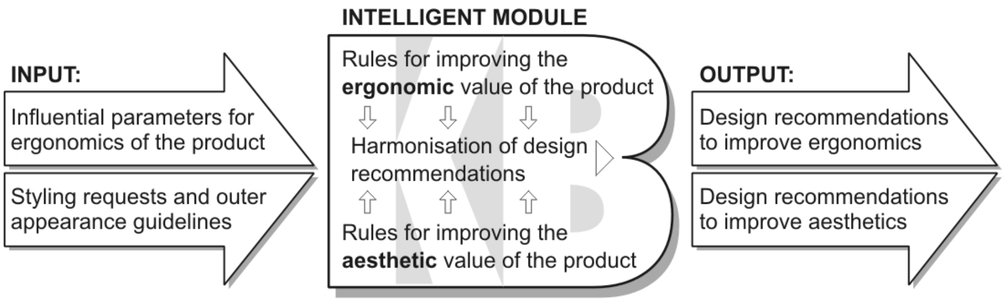

Fig. 4. Intelligent modules for aesthetic and ergonomic design support.

To assure the interdependent functioning of the modules, development of both modules will be carried out simultaneously, with special emphasis on achieving proper interdependence between the modules.

In order to have a proper control over each part of the system, both modules should have separate knowledge bases, containing the theoretical and practical knowledge about the design and redesign actions. When using only one module, the inference engine, common to both modules, will use only the knowledge base that belongs to the module used. On the other hand, when both parts of the system will be used, the inference engine will use both knowledge bases and perform reconciliation when needed.

Redesign recommendations will be proposed to the user by applying expert knowledge collected in the knowledge base considering case-specific data given by the user. Explanation mechanism will provide all the information needed to understand the background of the recommendations proposed.

Figure 5 shows the architecture and indirectly also the expected application procedure for the proposed intelligent modules for supporting the ergonomic and aesthetic design.

Intelligent module for ergonomic design should help the user during enquiry, selection and application of the ergonomic recommendations, which will be collected and encoded in its expert knowledge base. In addition to the knowledge base, the database with the appropriate anthropometrical records is also essential to be a part of this intelligent module.

Intelligent module for aesthetic design is meant to advise and guide the user during the aesthetic design (styling) phase of a product realization. To ensure the proper use of the expert knowledge in field of aesthetic design, the knowledge base with rules and recommendations regarding aesthetic design will be developed. Various important elements influencing the aesthetic value of the product, like proportion, harmony, direction, curvature, etc. will be investigated, collected and written into the knowledge base of this intelligent module.

We expect the proposed knowledge-based modules should increase the effectiveness of the product realization process and enable less experienced users to get qualitative results in the aesthetic and ergonomic design phase [14].

Fig. 5. The architecture of the intelligent modules for supporting ergonomic and aesthetic design.

6 Case study and expected intelligent support

Product development is above all decision making process. While designing new product, the designer has to make several essential decisions to acquire the most appropriate approximation to optimal product. An example of development process for programme-selection knob for the washing machine and possible application of intelligent advisory system is presented here. Preliminary conditions for start up the development process are unambiguous limits and requirements due to the geometry and function of the product.

First step is to design the aesthetic shape of the outer side of the knob. The designer presents a few versions based on experience and subjective judgment. Already in this stage of the process, the intelligent advisory system for aesthetic design would be able to offer the user recommendations according to the message that the product should send to the customer. Chosen shape should also be harmonized with ergonomic regulations where again the intelligent module for ergonomic design will be able to present some advice to the engineer.

Computational 3D model should be made after aesthetic and ergonomic design is concluded. The material selection is next phase in the process. If designer is acquainted with plastic materials for this kind of product, the decision can be provided relatively easy. On the contrary, the inexperienced engineer will have problems and here is the potential of intelligent module for plastic design, which would save designer's time by offering adequate recommendation. After analyses and simulations are evaluated, some changes like the wall thickness of critical positions (the lock tooth) at the backside of the knob or slight change of the material could be necessary. It is expected, the advisory system will provide adequate help again at this phase as also in the following one, when proper technological procedure should be chosen.

Figure 6 shows the cycle of development process divided to aesthetic and ergonomic design as well as functional design where the contribution of intelligent advisory system is represented in several phases of design.

The intelligent system will be developed in form of consultative advisory computer tool to be used interactively. The main goal for the system is to use domain knowledge for complex reasoning in order to provide qualified design recommendations.

In order to enable transparent and efficient system application, the user interface will be developed with a special attention. Regarding the type of input and output data, two different application modes are anticipated. Guided mode (question and answer) will be used mostly at the beginning, when first set of parameters has to be presented to the system. During data processing phase, the system may present additional questions or ask for more parameters. In this case, guided and graphic mode will be used to present the problem to the user. In final phase, the solution will be presented in graphic mode if possible.

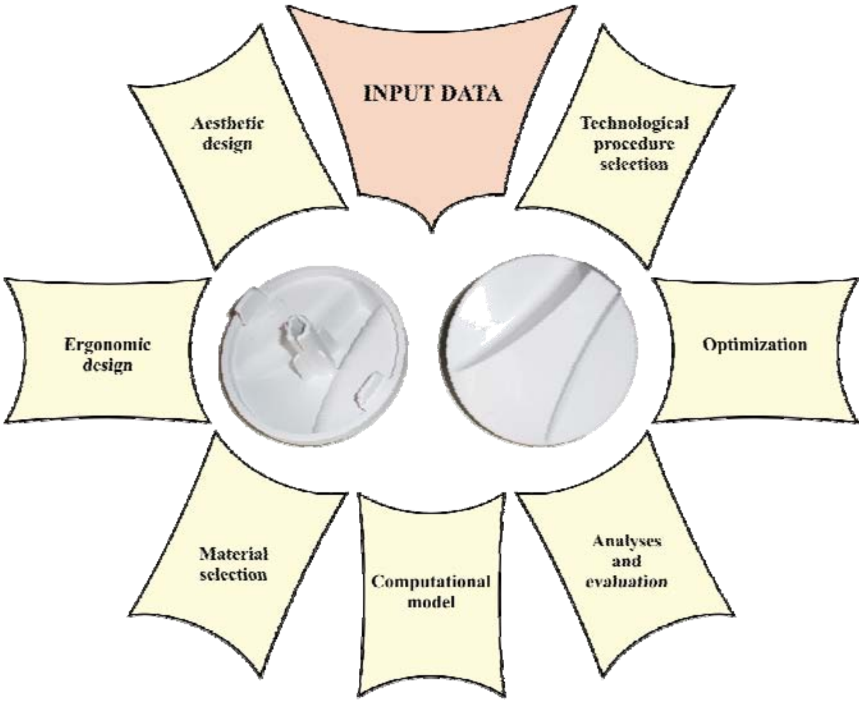

Fig. 6. Development process for programme-selection knob.

7 Conclusion

Engineering design of plastics products, guided with some specific design aspects, such as ergonomics and aesthetics currently still depends mostly on the knowledge and experience of design experts that contribute to the product development process. With development of the proposed intelligent advisory system, this knowledge and experiences will be collected, systematised and arranged in the module-based knowledge base. Findings and results of the research presented here (developed software) will benefit to the overall research area by encouraging development of additional intelligent modules to cover some other specific design aspects.

In developed world, the KBE techniques are already extensively applied in bigger modern companies related mostly to military, airplane and automotive industry. The awareness of the KBE potential benefits is also present in many small and medium sized enterprises that experience the need for this technology, but in many cases do not have enough human and financial resources to implement it into their product development process. Using the proposed intelligent system even smaller companies will be able to appear on the market with optimal designed products at relatively low development costs, which will decrease their prices and increase their competitiveness.

The research presented in this paper is a part of the broader research activities, performed by the members of our laboratory. The aim of these activities is to develop intelligent advisory systems for supporting product realization process. Our recent results in this research field are two prototypes of the intelligent systems, first to support finite element selection process [15], and the other to support design optimisation considering the results of the structural engineering analysis [16].

The proposed system is also meant to be used in education for the students of engineering and product design as typical representatives of inexperienced designers. In this case, the important feature of the intelligent systems that usually have the ability to explain the interface process will be especially welcome.

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