DESIGN VIRTUAL PRODUCTS USING HANDS

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ABSTRACT

The industrial design process mainly deals with the initial conception of the product. It is traditionally characterized by the production of several physical prototypes made by skilled modelers molding plastic materials with their hands. Their purpose is showing the product and also evaluating its shape. The production of physical prototypes and their integration within the downstream digital activities of the product development process include practices like Reverse Engineering that are costly and time consuming. Some other practices have been adopted in the last decade, where designers themselves use CAS (Computer Aided Styling) tools for defining virtual prototypes of products. Anyway, also in this case some physical prototypes are built for product evaluation and final shape assessment. An alternative practice based on the use of *virtual and haptic prototypes* is proposed by the EU research project T'nD - Touch and Design (www.kaemart.it/touch-and-design) financially supported by FP6 IST Programme of the European Union. The project purpose is developing a system that aims at offering the possibility to build digital models of products using interaction modalities that are typical of the production of hand-made prototypes. It will also be possible to evaluate the digital models of products by touching them with hands. The system is expected to be easy, intuitive and pleasant to use for both designers and modelers so as to convince them to adopt it as daily working tool.

The project has started analyzing the current design process of the partners operating in the industrial design sector, and observing how designers and modelers operate. The paper describes the design process and the observations performed at Eiger, one of the project partners, that is a Spanish company designing and developing household articles. Besides, the paper describes T'nD system concepts, scenarios and the first developed prototype, and discusses how the innovative T'nD system is expected to improve the design process of Eiger.

Key Words: Virtual prototyping, shape modelling, haptics.

Grupo Temàtico: Realidad virtual: modelado, animación, simulación y multimedia

1. Introduction

The industrial design process mainly deals with the initial conception of the product. It is traditionally characterized by the production of several physical prototypes made by skilled modelers modeling plastic materials with their hands [1]. Their purpose is showing the product and also evaluating its shape. The production of physical prototypes and their integration within the downstream digital activities of the product development process include practices like Reverse Engineering that are costly and time consuming [2]. Some other practices have been adopted in the last decade, where designers themselves use CAS (Computer Aided Styling) tools for defining virtual prototypes of products. Anyway, also in this case some physical prototypes are built for product evaluation and final shape assessment. An alternative practice based on the use of *virtual and haptic prototypes* is proposed by the EU research project T'nD - Touch and Design (www.kaemart.it/touch-and-design) financially supported by FP6 IST Programme of the European Union. The project purpose is developing a system that aims at offering the possibility to build digital models of products using interaction modalities that are typical of the production of hand-made prototypes. It will also be possible to evaluate the digital models of products by touching them with hands. The system is expected to be easy, intuitive and pleasant to use for both designers and modelers so as to convince them to adopt it as daily working tool.

The project has started analyzing the current design process of the partners operating in the industrial design sector, and observing how designers and modelers operate. The paper describes the design process and the observations performed at Eiger (www.Eigersl.com), one of the project partners, that is a Spanish company designing and developing household articles. Besides, the paper describes T'nD system concepts and the first developed prototype, and discusses how the innovative T'nD system is expected to improve the industrial design process of Eiger.

2. Industrial design process at Eiger

This section describes the industrial design process as it is currently performed at Eiger. The process involves several specialists, professionals and departments. The departments that are mainly involved are marketing, engineering and product design. In addition, other departments such as financial, quality, process engineering, logistics, and customers and suppliers are also involved. The various activities are organised according to a concurrent engineering structure. Usually, Eiger acts as an external design department, but with direct link to the customer companies.

Industrial Design is one of the activities within the product development process. It is quite independent but is nevertheless well integrated into the process of product generation. Industrial Design can be seen as a means and not as an objective, inside the context of product development. It aims at presenting new products to the market that incorporate value for the users, and consequently generate competitive advantages. The Industrial Design process at EIGER has a general structure that could be used for any kind of product, but is differentiated according to the following factors:

- Customer company typology;
- Technological characteristics incorporated by the product;
- Units to be manufactured / investments;
- Security and specific risk;
- Individual or collective use of the product.

Traditionally, the industrial design process includes various procedures, related to the application of methodologies and concrete techniques. They depend on the application of theoretical and empirical practices, as well as, on the types of the specific professional activity. The process has an iterative and heuristic character, where all activities are performed in a sequential way. This practice has been changing, in Eiger, approximately since a decade, as a result of the incorporation of new applied technologies, of the evolution of computer graphics, and because of the strategic competition. This new context has involved the introduction of practices of simultaneous engineering that allow carrying out activities in parallel instead of in sequence, and consequently reduces the time devoted to development and diminishes the uncertainty and the risk. Furthermore, it facilitates a more and more fluid communication between the agents involved in the process.

2.1. Eiger's Process Phases

The industrial design process is divided in several correlated phases. The phases consist of non-sequential activities. At the end of each phase, a problem is solved and a decision is taken. The process phases are the following and are subsequently detailed (Figure 1):

A. Information and analysis phase;
B. Concept definition and alternatives phase;
C. Definitive alternative development phase;
D. Industrialization and finalizing phase.

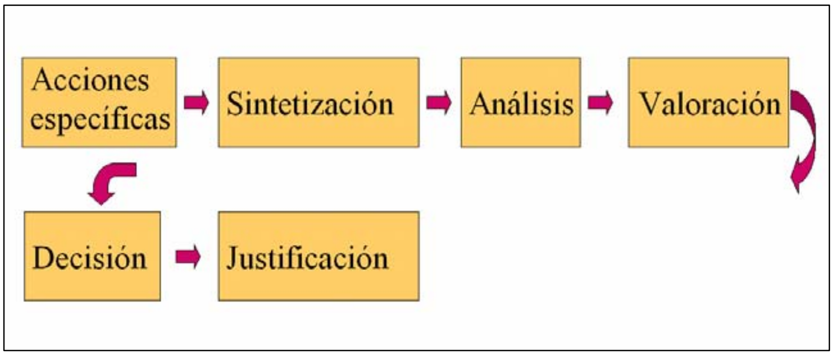

Figure 1 – Eiger's industrial design process including specific actions: synthesis, analysis, evaluation, decision and justification.

<u>A. Information and analysis phase</u>

The design process starts with some product requirements defined by the marketing sector, and with some basic industrial design specifications. This phase studies various aspects related to:

- Analysis of previous versions of the specific product and of the competitors' similar products;
- Study of market tendencies, market segments, range and positioning;
- Formal and functional study;
- Ergonomics analysis with a special emphasis in the anthropometry and the relation with biomechanics;
- Analysis of usage and usability;
- Solutions of QFD (Quality Function Deployment);
- Collection of information from consumers, research centres, fairs, exhibitions and congresses.

At the end of the phase, a report including conclusions is delivered describing in details the product design activities to perform in the subsequent phases.

<u>B. Concept definition and alternatives phase</u>

During this phase the possible concepts will be formalised, with general solutions that answer to the requirements specified in the previous phase and to its possible alternatives. A minimum of two and a maximum of five alternatives are selected for further development.

The design requirements will be studied, including aesthetic aspects, product shape and functionality, ergonomics and usage aspects, and in addition all symbolic and communication aspects. The specific activities of this phase are the following:

- Creative activities using sketching, mock-ups and models;
- Volumetric definitions using different CAS/CAD solutions;
- Accomplishment of technical documentation of support;
- Specific ergonomics and usability studies;
- Symbolic analyses and analyses of tendencies.

At the end of the phase, the concepts and alternatives selected according to the recommendations or suggestions provided are used as input for the following phase.
Alternative solutions are described by means of the following representation means:

- Formal models;
- General and detailed sketches;
- 3D models;
- Technical documentation, initial (overall) measures.

C. Definitive alternative development phase

On the basis of the alternatives selected in the previous phase, we will proceed with the detailing of the design, especially for what concerns the aesthetic aspects (colour, texture and shape). This is done taking into account the recommendations of Product Engineering Department who gives indications about materials, manufacturing processes, costs, and also the necessary volumes for the placement of internal technical elements, as well as assembling constraints.
All these activities are carried out using the following supports:

- Formal and functional models;
- Volumetric definitions using 3D CAS/CAD;
- CAD/CAE to assure geometries on the basis of the requirements;
- Definitive technical documentation.

At the end of the phase the results and all the documentation will be analysed by the Product Engineering Department to check compatibilities of those product aspects which are interrelated with the industrial design phases.

D. Industrialization and finalizing phase

In this phase the design activity is concerns those modifications required because of difficulties in the industrialization, production using selected materials and manufacturing processes, and assembly of the parts and components of the product. Several tests will be performed, and also evaluations made through rapid prototyping, preliminary series and mock-ups of functional models. Besides, during this phase packaging and instruction books are usually developed.
All these activities are carried out using the following supports:

- Prototypes, rapid prototyping or functional models;
- Definitive technical documentation (as built);
- Laboratory and market tests;
- Definitive visualization and 3D models;
- Results of the tests of quality and reliability;
- Analysis of perceived quality of the design.

The described industrial design process is a general process that can be subject to variations, according to the typology of the product. In general, as a rule, all the products will follow this process. Figure 2 shows the design activities carried out for the design of a specific product: a vacuum cleaner.

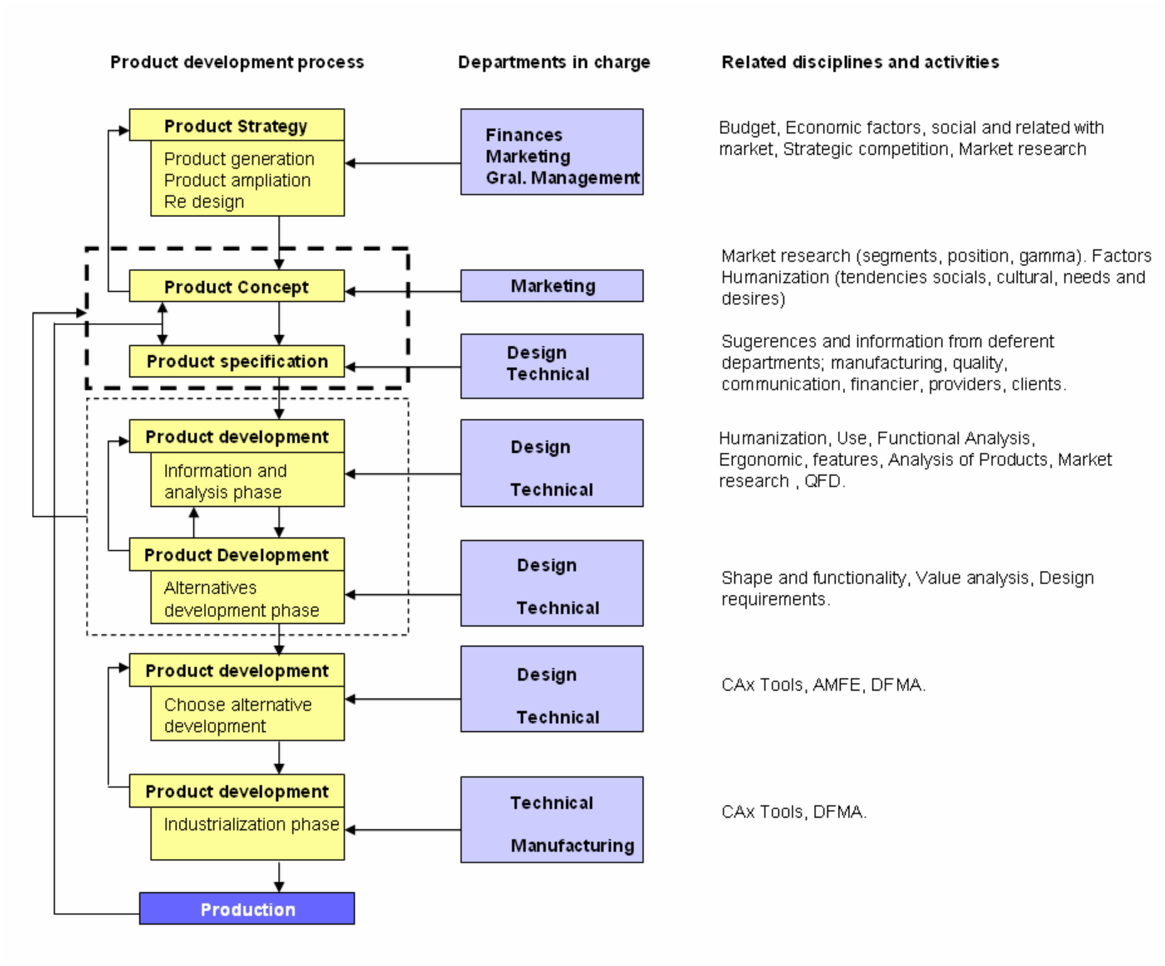

Figure 2 – Eiger's design process phases for a specific product.

2.2. Critical aspects of the process and expectations

The process described in the previous section has several problems and critical aspects mainly concerning the tasks and tools used. Some critical aspects of the process are the following:

- Create a good product design specification (PDS)
- Understand the PDS
- Generate ideas really adapted to the PDS
- Generate good criteria to select models to develop
- Make the models understandable by the customers

Some critical functional aspects of the modeling technology are the following:

- Sketching ability
- Realistic 3D visualization
- Technical approach capabilities
- Process for making physical mock-ups from 2D and 3D models

The industrial design process as it is today requires being more efficient and effective. It is evident that the best way to optimize and improve it is avoiding iterations and returns to the initial conceptual phase. It is important to save time in all tasks involved in the process, and reduce the number of design supports (sketches, physical mock-ups, models, etc) used to define the product.

Eiger expects that in the near future it will be able to develop products in a shorter time. For that, user-friendly technology should support the various design phases, from conceptual to detail design phase. The learning curve of the technology should be as small as possible. The product being created should be continuously evaluated both manually and through vision. It is expected that designers' knowledge and skill is well exploited by the technology supporting the design phases. The complexity of surfaces supported by the technology should be such that any product can be represented.

3. Improved industrial design process

In order to overcome the problems of the industrial design process listed in the previous section, a new free-form shape modeling system has been conceived within the framework of the T'nD - Touch and Design project (www.kaemart.it/touch-and-design). The system should satisfy the following requirements:

- be usable by both designers and modelers, exploiting users' skill;
- allow designers to create, modify and evaluate a shape using a monitor or a 3D display for seeing the product, and some haptic tools for touching it;
- provide shape modeling operators that are intuitive to use, and provide in output high quality surfaces (class-A surfaces) immediately re-usable with CAD tools.

The conceptual design process based on the use of the T'nD system is shown in Figure 3. The system is used by designers or modelers for creating, modifying and evaluating the product concept. They operate using vision and touch for creating shapes starting from initial ideas and concepts. The system generates models that are physical and digital (high quality surface). To note that in the proposed process physical models are always the results of virtual prototyping.

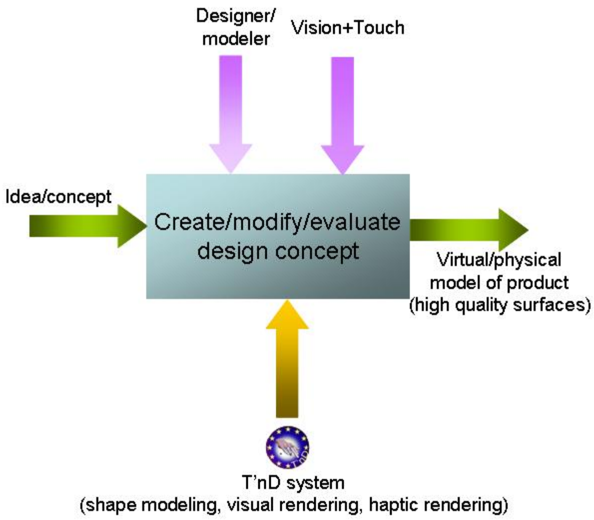

Figure 3 - Conceptual design process based on the use of the T'nD system.

3.1 Expected benefits

The use of the system would bring benefits to users and to the overall design process. The system provides some operating modalities that are familiar to modelers, since it resembles the actions they do in the workshop for building physical prototypes. The T'nD system is conceived to be an everyday working environment that designers and modelers find easy and intuitive to use, useful and productive, and without having to bother about technological aspects, but instead being concentrated on creative activities. Users have continuous contact with the object shape during its creation and evaluation. Easy-to-use and natural interaction techniques will convince designers to make use of digital tools on the basis of physical skills that can be used in an efficient and effective way for performing their job.

The T'nD system also improves the product design process making tighter the integration of creation and validation activities, allowing for the creation and validation of more ideas and therefore improving product design quality, and finally reducing time and efforts devoted to making physical prototypes, and for surface reconstruction since the digital model is ready to use for subsequent detailing design activities. Furthermore, the system facilitates communication between different departments (mainly design, engineering, and marketing) since a unique digital object is provided, instead of supplying physical and digital prototypes made with numerous and different types of techniques.

4. Shape modeling system based on haptic interaction

In order to design a shape modeling system that satisfies the mentioned requirements, we have 1) analyzed the users' skill while molding physical prototypes using hands and identified actions to reproduce in the system; 2) designed innovative haptic tools supporting the modeling actions; 3) study new shape generation methods. On the basis of these studies, the system architecture has been defined, and a first prototype of the system has been implemented.

4.1 Users' skill analysis

In order to design a system that can be easily used by modelers and designers its functionality should resemble the usual actions performed by those users. To acquire information about users' actions modelers of end-user partners have been recorded and interviewed while creating physical models of some selected objects by working malleable materials (like clay, foam material, etc.) with their hands. Subsequently, the collected material has been quantitatively and qualitatively analyzed in order to understand the advantages derived from using hands when creating shapes, and to understand the modelers' haptic knowledge that is tacit and difficult to capture. The tools used (manual tools, machines), the gestures and hand motions performed (for shaping the object, for feeling the surface quality), the process tasks (template preparation, preliminary material removal, precise sculpting, surface finishing, comparison and measurement, visual and tactile assessment) have been analyzed and classified. Modelers and designers claim that visual, tactile and haptic feedbacks are equally important in the shape creation and evaluation process. The skilled hand motions performed by the modelers allow for a precise creation of the shape, the tactile interaction with the object helps in comparing adequacy of the physical prototype with the drawings, in providing early clues about shape features, and in improving the 3D mental representation of the shape. At the end of this phase the following manual operations of interest for the project have been selected: *scraping, surface quality testing and finishing* (shown in Figure 4).

Figure 4 - Users' actions implemented in the T'nD system.

4.2 Innovative haptic tools

In order to define the appropriate haptic tools satisfying the system requirements, a survey of state-of-the-art devices has been performed. Some benchmarking has been performed on current available technology, considering haptic performance indicators such as workspace, position resolution, stiffness, nominal forces, and tip inertia, and also some non-dimensional performance indicators [3]. Since the objective of the project is to create an interface that allows designers to interact haptically and graphically with virtual models of products including a true size car body, purely point-based haptic interaction is not sufficient to appreciate and modify the surfaces in an intuitive way. Designers wish to interact either with the full hand, or with a virtual version of typical material modeling tools. Satisfactory full hand interfaces (haptic gloves) have not been built so far, despite a number of attempts and one commercial product, the Immersion CyberGlove (www.immersion.com). This is probably a bridge too far at the current state of the art.

On the basis of the state-of-the-art [4], the final conclusion highlights that an extended version of FCS HapticMaster (www.fcs-robotics.com) is the most appropriate hardware solution for the project. Currently, it is the only device which offers adequate strength in an acceptable price bracket, but it is currently a 3-DOF to 4-DOF device. Within the context of the project, the FCS HapticMaster can be used as basic platform, equipped with a strong and stiff 6-DOF device carrying a simulated clay modeling tool. A first prototype of the haptic system has been developed using two HapticMasters to drive a 5/6-DOF end-effector.

4.3 Shape generation methods

From the point of view of shape modelling, the project aims at defining a technique for shape generation and modification allowing a fine control of aesthetic properties of shapes. The technique should support the integration to the T'nD haptic system, and on the other side should interface to standard CAD data models. Several approaches for shape modelling techniques exist in literature, ranging from purely geometrical representation up to physics-based approaches. Some recent techniques for shape generation/modification are particularly interesting for T'nD project: voxel modelling and "swept volumes" techniques [5, 6]. There are also some commercial products that use methods for shape generation, as said, sweep or voxel-based. In particular, one commercial CAS system exists that is based on a haptic exploitation of a voxel representation, namely *Freeform* of *SensAble technologies* (www.sensable.com). It uses classical shape generation tools, based on extrusion or rotation of profiles in order to "save time" by allowing the user to define an initial block closer to the final expected shape. Considering the types of objects that can be modeled it is clear that the high aesthetic quality level required by the car industry or high-end customer products is not reached. Besides, some recently developed physics-based methods represent any object as a dynamic system subjected to internal interactions depending on materials, and external forces [7].

On the basis of the state of the art analysis, we conclude that the emerging technologies that the project investigates and develops include sweep-based and voxel-based techniques. The major open issue concerns the definition of an appropriate theory allowing discrete schemes to support fine quality shape generation. The project is developing haptic-based motions and sweep methods supporting the identified actions.

5. System prototype and testing

The idea of using a haptic tool for modeling objects in the industrial design field is quite new. Therefore, we have considered very important testing the concepts and interaction modalities proposed by the research with designers in order not to build a system that users won't like, and consequently won't use. Therefore, in order to test the concept of haptic "scraping" in the virtual environment, we have developed a prototype that can be evaluated by end-users.

The system set-up consists of an initial version of the scraping haptic tool driven by two integrated HapticMaster devices (so as to have a 4-5 d.o.f. haptic system), and a monitor showing the object virtual model. The developed example aimed at just validating the general idea. Therefore, in this first implementation the system shows a simple geometric object. The user handles the haptic tool with two hands like in the real case when using a scraping tool, and moves it for removing material (Figure 5). When the haptic tool gets in contact with the virtual object, it gives back the user a haptic feedback. The tool is equipped with some buttons on its back side that allow the user to change some physical parameters of the models. The two buttons placed on the right hand side of the tool allow the user to set the stiffness of the material. The two buttons on the left hand side allow changing the resistance of the material when scraped.

Some users have been invited to try and evaluate the prototype. They consist of designers and CAS/CAD engineers. They all agree on the fact that the system is suitable for rough shape creation. Conversely, few of them seemed not fully satisfied concerning the possibility of creating precise shapes. For what concerns this comment it is important to underline the fact that the current implementation of the system does not provide a graphical feedback of the result of the actions of the users, and also no stereo vision has been yet implemented. That might indeed limit the possibility to interact precisely with the object model. In general, all the testers have expressed the opinion that the system might be a very helpful tool both for modelers and designers. They all seem quite positive in the possibility of integrating this new tool with other modeling tools within the design process. At the moment, testers do not see the possibility to replace 2D sketching or 3D CAS tools, but rather they confirm the effective use of this tool for substituting the physical model making. Concerning the system usability, they all agreed in confirming its extreme intuitiveness for creating shapes, also because of the intrinsic naturalness of the hand gesture. An important achievement to be noted is that all participants considered the motion they were making and the forces implied of extreme good quality, absolutely similar to the ones of the physical clay model making.

Figure 5 – An end-user testing the first prototype of the system.

6. Conclusions

The research work described is still in progress and aims at developing a new system based on the concept of creating and testing digital shapes using haptic tools similar to the ones designers are used to use in the shop floor for creating physical models. That aims at providing a system that designers -who typical are creative people with no expertise in technical matters- find intuitive, familiar and enjoyable to use. The system implements all positive features of modeling tools that are not available when working with physical models by hands – for example mirroring and scaling- and at the same time it allows designers to work with hands for creating an object shape by removing material, and for testing its surface by physically touching it. In addition, the system provides in output a precise digital model that is immediately usable in downstream design activities.

7. Acknowledgement

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