TOUCH AND DESIGN

DEFINITION OF SCENARIO AND TEST CASES

by
Monica Bordegoni (Politecnico di Milano)

Abstract
This document describes the scenario and the test cases. The scenario depicts the evolution trends of haptic and shape modelling technology, the expectations of end users, and short and long-term visions about new systems for shape modelling based on tactile feedback. Test cases describe the tests that will be performed in order to assess the project system concepts, the prototype, and the final version of the T'nD system. Besides, some parameters for measuring the process performance, and system functionality and usability are presented.

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Author:	**M. Bordegoni**	**Politecnico di Milano**	**WP leader**
Approved By:	**U. Cugini**	**Politecnico di Milano**	**Project Coordinator**

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0. Index

1. Extended Summary

This report presents the results of WP4 – Definition of Scenario and Test Cases, dealing with the definition of Scenarios and Test Cases.

The approach followed is described in the IDEF0 diagram [1] shown in Figure 1, and is reflected in the content of this document.

We have firstly analysed the IT partners' point of view regarding the long-term evolution of technology in shape modelling and haptics areas, and regarding the technological goals that they expect to achieve in the framework of the T'nD project (Activity A1 in the diagram).

In parallel we have analysed the end-users' point of view regarding current product design processes they have in their companies (As-Is processes) and tools they currently use to design products. Besides, we have investigated end users' ideas about how the process performances could be improved (Should-Be processes), and ideas about how the technology should be improved (considering both functional and usability aspects) in order to better fulfil their needs (Activity A2). At the end, a synthesis has been done concerning the end-users' product design processes, concerning critical aspects of those, and end users' needs and requirements demanding for improvement of process and technology.

On the basis of the input coming from the two activities A1 and A2, we have identified general requirements for a future system fully satisfying users' needs, and a subset of them that are planned to be satisfied by the T'nD prototype system (Activity A3).

The general system requirements are used for defining a future and long-term scenario. The T'nD system requirements are used to define the T'nD short-term scenario that includes feasible functionality and technological solutions that can be achieved in the timeframe of the T'nD project (Activity A4).

In parallel, a metrics is developed for measuring the benefits of the new T'nD process and for evaluating the T'nD system functionality, usability, performances, etc. (Activity A5).

Finally, from the T'nD scenario we derive some Test Cases that will be run at the end of the first year project (in WP3) in order to proof the system concepts and the proposed solutions, and at the end of the project (in WP7), in order to validate and evaluate the T'nD system (Activity A6).

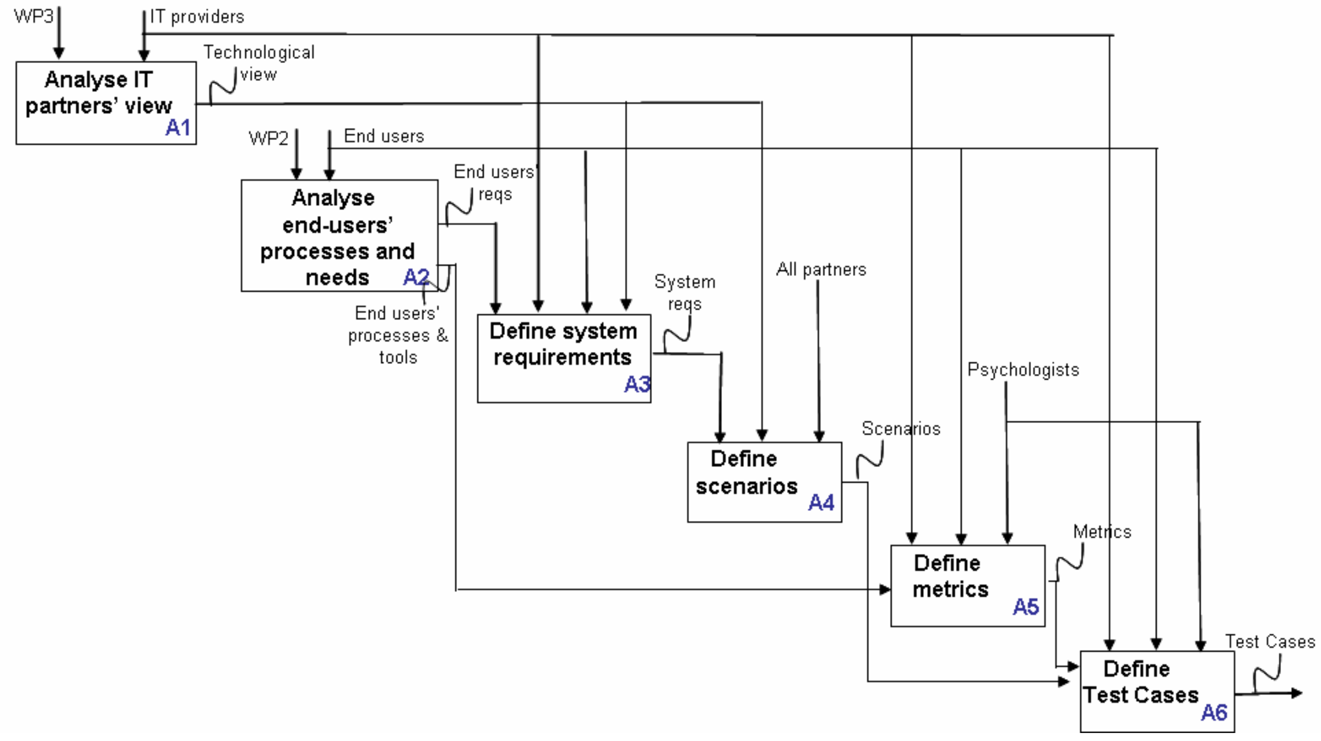


Figure 1. Diagram showing WP4 activities.

2. Evolution trends of technology

2.1. Introduction

This section includes long-term visions provided by T’nD IT providers concerning the developments of shape modeling and haptic technology. According to the trends, this section also describes the technological goals that are expected to achieve in the frame of the T’nD project and that can be considered some steps forward the target of long-term vision.

2.2. Evolution trends of shape modeling technology

2.2.1. Long-term trend

think3 vision of shape modeling technology is oriented toward the easiness of the tool and the quality of the resulting shape. The resulting shape modeling tools should be accessible to **any** user as **early** as possible in the design process. The user’s creativity should be enhanced by using T'nD, but of course it should not be slowed down, nor limited by the underlying mathematics whatever their complexity might be. The resulting freedom must not exclude the numerical quality of the produced shapes that should be ready for a CAD use. Moreover, it should be stressed that although a digital tool, T'nD will bring back to the designers the full bodily and haptic experience and fun they enjoy with hand drawing and hand modeling.
Techniques based on simulation of physical phenomenon or manual works are closed to the users’ understanding. They do not constitute the only possibility to reach the above described criteria but fulfill them. In particular the simulation of the clay scraping as practiced in the (manual) modeling workshops by moving /sweeping shaped-templates allows a good and direct control of the final shape generation versus other techniques (e.g. subdivisions).
In combination with the shape generation tools, and in order to facilitate the shape modifications (slight or radical) the technology should also fulfill the same criteria. The scrapping techniques can also be used here. As a matter of fact the corresponding shape generation is a modification by scrapping of an initial shape.
Therefore, the shape generation based on sweeping techniques should in our point of view play an important role in the future. Such techniques are not that new (some research studies have developed techniques for volume sculpting and morphing based on voxel modelling [2, 3, 4]), yet their utilization in quality shape modeling is still limited due to:

- The complexity required to define the right motion (sweep) i.e., the one that give the right shape.
- The mathematical complexity to express the result of the sweep such that it can be reused in downstream treatment.
- The inertia of the industrialists who are supposed to provide such tools.

2.2.2. T’nD technological goals

In T’nD, we intent to address some of the reasons that limit the utilization of the sweeping techniques for shape modeling.

- Based on user’s motion capture and identification we will identify some specific sweeps related to selected domain of product design thus facilitating the motion control.
- These specific sweeps will be studied and solved. They will be mainly dedicated to the sweeping of thin rigid templates. We endeavor to consider also flexible thin template.
- The mathematical expressions will be based on approximation techniques when relevant.

2.3. Evolution trends of haptic technology

2.3.1. Long term trend

Haptic technology has started out in the 1980's with relatively large and crude force feedback devices, with limited freedom of movement and a lot of resistance. It has since then evolved into usually smaller and lighter, but for the most part really quite similar devices. The improvement over the past 20 years has mainly been in minimizing the resistance or "impedance". Haptic devices are still point based, i.e. they offer to the user the feeling of a single point of resistance, much like the tip of a pen or of your finger.

Efforts have been made to add powered rotational degrees of freedom, grippers, and powered and unpowered gloves, but the results are still relatively primitive, both in the feeling presented and in the software supporting the shape rendering.

It is hoped that the next ten years will see a development where these point based interfaces are developed into "true" six degree of freedom functionality, plus a grasping interface for at least two fingers (thumb and index finger) or the approximation of a full hand grasping. This amounts to expanding the single point of contact based interface into a two point of contact interface. The grasping interface will allow more intuitive and realistic handling of objects in virtual space. In the even longer term, one or more extra points may be added to include the palm of the hand to emulate full hand grasping. All of these options are really extensions of the current paradigm of point based kinesthetic (i.e. muscle force feedback) devices.

In addition, research effort has gone into providing the sense of tactile feel to the skin surface. This will provide the feeling of the texture of a surface, usually at the level of fairly large and simple bumps, such as in palpation of tumors by the doctor's finger tips. Researchers like Hayward [5] are working on tactile displays, others on grippers. Their efforts are partly aimed at brute force methods such as modifying the shape of a membrane under the finger by an array of pins under a flexible surface, and partly aimed at simpler mechanisms which make clever use of the limitations of the human sense of touch. First examples of tactile displays, also named haptic windows, have been studied since 1995 [6, 7]. Hopefully these researchers will succeed in building devices that are usable and cheap, which are small and have very limited movement, and may still give valuable "impressions" of tactile touch without actually emulating the full complexities of the real world. If simple and light enough, these tactile displays could be placed onto the finger contact points of a conventional, multiple point based kinesthetic haptic device, allowing it to render the complete sense of feeling both the inertial features and the surface texture of a virtual object in a single machine. These general purpose haptic interfaces will in all probability be very complex and expensive devices.

A different approach would be to design dedicated interfaces for specific applications. Touch and Design project is a prime example of this approach. If the user interacts with the real world through a certain tool (such as a rasp), then it is more to the point to simulate the interface from the user to that tool, than from the user to the virtual world directly. Conceivably, a different haptic device would be used to simulate rasping the surface, and to simulate feeling the results with the fingers. After all, the tool is put down or even the other hand is being used to switch between the two tasks in real life.

Psychophysical research would be needed to find out whether the place where the two sensations are presented need to be the same, i.e. collocated, or whether it can be tolerated that certain sensations are presented in a different location, or even in a different modality. Psychologists and users may be even able to think of new metaphors which are easy to acquire, yet do not require actual (large) forces.

It would be expected that the largest breakthrough should come from the psychologists, or maybe the designers themselves, once they get their hands on T'nD "first generation" haptic modelling tools.

Figure 2 shows the evolution of haptic technology represented using evolution curves. Current technology provides point based interaction hpatic devices. The technology has reached a good level of maturity. The T'nD project consists of an incremental evolution of the current state of point based technology. A completely new technological approach, based on haptic window, has been addressed recently, and seems very promising in terms of tactile interaction and perception, and therefore, it seems the research and devlopment trend to follow in the next years.

2.3.2. T'nD technological goals

Certainly the first step in creating the haptic interface of the future is to build the simulation of the use of physical shaping tools. This tool needs to be built in order to be able to optimize it and do the psychophysical research on it. After it is perfected, it will be more obvious what modalities the users are still missing, and an effort can be made to make the next step, probably that of judging the surface by a tactile interface.

The achievement of T'nD will be to make a definite step forward in the simulation of tool use, both mechanically and in terms of rendering software. A clay modeling tool will be simulated, not just as a point based interface, but also in rotation (rolling and tilting). Contact forces will be calculated not just for a point, but for the complete line of contact between the tool and the clay model, and contact forces will include an intuitively appealing rendering of the actual forces in modeling the clay. This new device will convey to the user the full sensation of handling a tool in six degrees of freedom, and serve as a platform for psychophysical research into the use of tools, and of the sensations which can and cannot be conveyed through tool use.

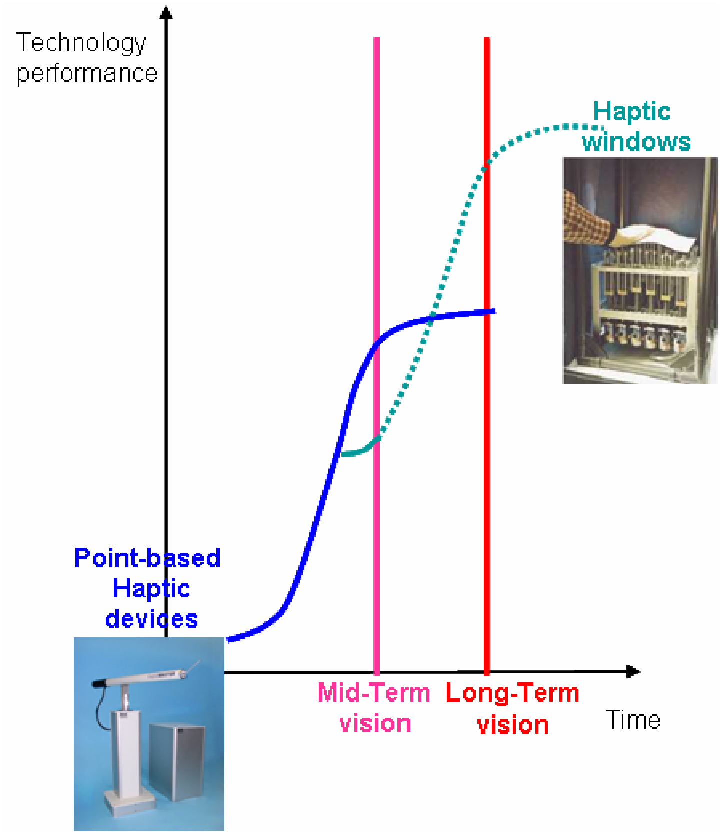


Figure 2. Diagram showing technological trends in the haptic domain.

3. Users' expectations and requirements

3.1. Introduction

This section is mainly compiled by end users and describes the product design processes at Alessi, Pininfarina and Eiger, and lists the critical aspects of the analyzed processes that might require attention in order to be improved. Besides, end users are asked to present their expectations concerning how the design process phases could be improved and optimized, and to describe technology (metaphors, techniques, tools, and devices) that they dream of or would like to use in future so as to fully satisfy their needs. The end users' processes have been synthesized into some scenarios, named *As-Is Scenarios*, and a general list of critical issues related to both processes and tools is compiled. In addition, a list of users' requirements is provided.

3.2. Alessi

3.2.1. Design process at Alessi

Description of current design process

In order to explain how Alessi works in the new products development, we underline that today we are using different ways to think and industrialize a new product, particularly at the beginning of the design process. In fact, if we consider that Alessi works with a lot of external designers and architects all over the world -using different processes to think and perform new designs of the object and each of them using different way to explain and present their projects, when we start to manage the project we have to adapt the designer's input to our own process. Therefore, we can have in input different materials: physical samples, pencil sketches, 2D drawings, 3D CAS or CAD Model (in bad or good quality). Obviously, we must adapt the input that we receive to our own industrial process in order to give at end of the development phase all materials (drawing, sample, moulds, tools) in order to start and maintain production.

Nowadays, the process of a new product design development follows a horizontal structure, which can be seen as well as a sequence of steps, if the new product is relatively simple to develop, but with continuous recall at the previous phases if the object is more complex to develop. In order to give some examples if we have to think, develop and produce a *tray* (usually it is a simple object to understand and produce) we know exactly the sequence of tasks that we have to carry out in order to achieve the final product, but if we have to develop an *handled vacuum cleaner* (not very simple object to understand in terms of style, ergonomics, engineering) we know how to proceed, but the typical sequence of tasks cannot be used, because we have to merge some of them at different levels (i.e., the designer cannot think about a new shape without taking into account some standard engineering solution, and vice versa the engineer cannot be free to work on styling aspects without the designer's approval). Therefore, when Alessi works on a complex new project, we have to introduce several loops of iteration between all the actors involved in the process. The result is that the stylist must think back at the shape of the object, marketing must explore what the followers do, and the engineer must think again what it the best solution, in terms of time and cost, in order to achieve the final product. Of course, we use a lot of tools at a different level in order to finalize a new product, Rendering and graphics tools, and CAS for styling, CAD for engineering, CNC for molding and prototyping, Rapid Prototyping, but again today we use a lot *hand made model*, built directly by stylist, usually in malleable materials and low quality of execution (this sample just aim to show us the design intent of the product), or built by our internal modeler, usually in rigid resin and high quality of execution. Above all, in this case we introduce the first loop of design, because the modeler generally has to understand through not very accurate sketches what the stylist really wants.

Concerning the T'nD specificity we need to focus our work in the creation – evaluation – modification phases defining what Alessi receive in input and what the development area must provide in output in order to achieve the final target. At the end we can understand how T'nD can be used as a complementary tool in our standard process, and where we can improve it in terms of quality of results, time and costs.

Sequence of Activities

The following table will show the abstract of our process, users, activity and tools used today. We put the focus just in the concept and development area where T'nD will find its natural application. In addition, we plan to explain why the quality of materials in input can influence the development process.

All these phases must be considered as a merged phase, because we cannot afford to spend time to wait that the previous will be done and frozen. We can do it only when the input and the tools used are of high quality (3D model by designers, with surface representation) because after that we can use a "*digital process*" (3D model, 1st engineering / marketing evaluation, rapid prototyping, mould design, etc.)

We can assert that if the input is "*high quality input*", the process to achieve the new product development will be linear, understandable, with low number of loops of iteration between the users, and as a consequence we spend less time and money to achieve a new product.

When we are forced to put in our process "*low quality input*" (hand made model, 3D model built by meshes) we need to add at our process a "*reverse engineering phase*" usually expensive in terms of cost and time but over all without added value. Above all, the number of loops of iteration especially between us and the stylist increase.

Of course, for our philosophy, we do not want to force those designers that want to work with several physical models and want to have the physical perception of the shape towards the totally digital approach with CAS, (a lot of them could not accept it).

The yellow (light) areas of the following table underline the "*low quality input*" and the "*non-efficient*" process.

Users	Concept Design (Input)	Evaluation (input & output)	Engineering (Output)
	Stylists, Designers, Architects	Design Assistant, Projects Managers, Marketing, Modeller, CAS/CAD users	Engineer CAS/CAD/CAM Users Buyers Modeller Mould Makers
I/O High quality input for the process	**3D models by surfaces** **2D vectorial drawings (for very simple and geometric object)**	**Feasibility study** **Model of style by Rapid Prototyping or CNC technology** 3D checks and modification Marketing test Economics Valutation	Product definition: High Quality 3D model with detailed engineering. 2D drawings (for documentation) **Final prototype for validation** Packaging and Instruction Rendering for copyright and market presentation Production cicles Molds for production
I/O Low quality input for the process	Hand made models Hand made sketches **3D models by meshes** 2D raster drawing Pictures **2D vectorial drawings**	Hand made models Reverse Engineering	Reverse Engineering
Tools	Rhino 3D, Alias Wavefront,Maya **Z form, Z brush, 3D studio, Maya** **Autocad** Adobe illustrator, freehand Paper and pencil Expanded Polistirolo Rigid Resin Malleable Materials	Thinkdesign Milling machine, stereolytografy, stratasys etc. Hand tools	Cas/cad/cam 3D/2D Thinkdesign Edm tools Graphics tools (for packaging and instruction) PDM for production cicles and product lifeclicle management

We think that the T'nD project could solve this situation. In fact our target will be to bring the "*low-quality input*" (yellow areas) at the "*high quality input"* (violet areas), and above all, to uniform with our" modern industrial process".

Metrics

In order to give some metrics to evaluate the different approaches concerning new product designs we explain using two examples why the quality of input can influence the designer's decision and as a consequence the number of iteration loops.

Examples:

1 st approach • Designer creates several hand made sketches and we decide to take into account two proposals • Designer make a physical model	• We have to interpret the sketches, evaluate the product, and make a feasibility study and the build first prototype. If the first prototype is made by hand (we prefer this way with this design approach) after several loops of shape evaluations and manually improvements we have to do a reverse engineering phase in order to have a digital representation that will be use for an engineering phase. Usually it is very difficult, because we can be free, but several times we do not reproduce the right idea of the stylist. • When the designer makes a physical sample we have to do a reverse engineering phase. • In both approach we can't take into account the engineering constrains in a precise way.	**Pro : the designer and us can touch and feel the object (constantly), the ergonomics problems can be checked and solved immediately** **Cons :The average time used to develop a new product using those approach is 18 months.** Why: the communication between us and the designer is possible only via hand made model, that usually don't take into account a lot of engineering constrains (parting line, internal parts etc.). It is very difficult to make the designer to do some modification / improvements because we can't be very punctual on our requirements. We can be punctual only if we put the sample into a Cad system thorough a Reverse Engineering phase. Numbers of loop: from 6 to 10 used for style improvements and engineering optimization. This process usually is very expensive.
2 nd approach • Designer creates several 3D high quality models. Digital approach • Designer creates a very accurate 2D drawing (usually to represent a very simple and geometric object)	• We can be free to choose the best way to build the first prototype (Rapid Prototyping, CNC etc.), to start with the pre-engineering phase, to give material to the marketing, and we can manage the improvements loop using a 3D data. • We can make a 3D model without interpreting the design intent	**Pro**: The average time to industrialise a new product is decreased down to 12 months. We do not have a reverse engineering phase. From the start to the end the process is uniform (High-quality input) The number of loops is from 2 to 4 **Cons**: we cannot have the possibility to interact constantly with the model in terms of touch and feel the shape. One of the most critical aspects is concerning the ergonomics problems

Analysis of critical aspects

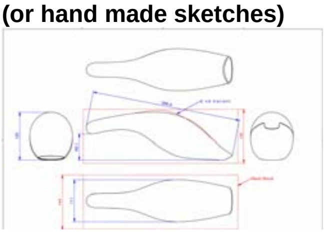
- The most critical aspect of this process is that in both cases we have to use the physical prototype, also in the second approach. For sure, it is less expensive in terms of processes build a prototype thorough rapid prototyping or CNC.
- In the first approach there's no connection with the actors of the process (stylist/modeler, CAS/CAD users). We can make this connection just to add a reverse-engineering phase
- The utilization of a hand made sample increase the general time of evaluation of the engineering aspects.
- The loop of iteration make difficult the project management.
- Concerning the second approach, for sure that it is less expensive, but several times it is not the best way to think about a new product.
- Some functions used to create the first 3D model are not very easy to understand by non habitual CAS/CAD users (a lot of stylists do not want to use CAS approach).
- Some CAS tools are using a "mesh" representation (Form-z, Maya, Z-brush) and a lot of stylists prefer to use this representation because is more "malleable" than a surface representation, but after that we have to translate the mesh into surfaces (*reverse engineering without digitalization*).

3.2.2. General expectations

How to improve the process

If we can introduce a novel system based on digital representation in each parts of our process where it is preferable to have a physical approach with the new products (*hand made model*) and where we need constantly to "*feel*" the object, for ergonomics aspects in example, able to make simple the first creation by the designer or the modeler (*easy to use is mandatory*) and give us the possibility to re-use the data (*high-quality output*) in the engineering phase, end give to the designers the possibility to use the engineering data to make some improvements (*loops*), we can be sure to cut the time to market, by loop decreasing, uniform process, delete reverse engineering phase in every new project.
Moreover we can use some old-skills (modeler) in the new way, with the best integration with modern process of new product development.

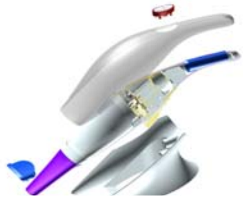
2d Drawing From designer (or hand made sketches)



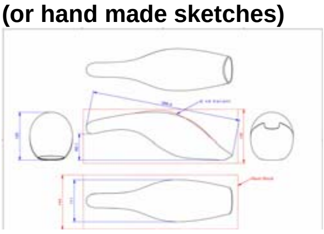
Hand Made model by designer or modeler

Reverse engineering in order to make a virtual model (For CAD needs) Critical Aspect: Cost and Time. Low added value

Product engineering using CAS/CAD tools

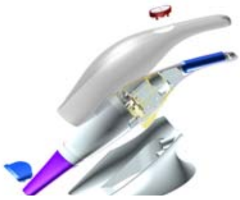


2d Drawing From designer (or hand made sketches)



Model made with T'nD in Alessi

Product engineering using CAS/CAD tools



Expectations about technology

We can divide our expectations about technology in medium and long term target:
At medium term (at the end of T'nD project) we want to understand if the haptic technology and the surface creation in connection with the haptic, could be used in the future, in terms of quality of output, what really we can feel and how we can interact with the virtual prototype.
Our long term expectations, obviously it depends on T'nD project results, is to use this technology at every level of our process (design creation, modification, evaluation, ergonomics, marketing), and substitute the physical model, at least at the beginning of the project.

3.2.3. Alessi requirements for T'nD

Our requirement for the T'nD project, in order to validate the technology, is to re-make our test case (handled vacuum cleaner) using T'nD tools (FCS - HapticMaster and novel surface generation systems). Obviously we don't want to reproduce all the gestures that can be seen in the test case films (the hewing of the parts is not interesting, but it is very interesting the finishing of it).
We want to have an High-quality output (manageable surface, needs for CAD when we have to engineering the object introducing shell, fillet, rib, etc.) and from T'nD point on view the possibility to re-use the data from a CAS/CAD systems (loop of iteration/evaluation). We also want to check how could be the perception of the model passing a virtual handle on it. Our modelers will try T'nD system in order to understand if in the future it will be possible to change from hand-made sample to T'nD approach.

3.3. Pininfarina

3.3.1. Design process at Pininfarina

Description of current design process

The main tasks of Pininfarina design process are the follwing:

1) RESEACH AND DESIGN CREATION
2) SURFACE CREATION
3) MODEL CREATION STEP 1
4) MODEL CREATION STEP 2

The style creation process starts both from a customer request and from a specific Pininfarina Board Direction demand. In both cases, the basic data are listed in a product briefing whose level of detail depends normally on the customer, independently from the briefing origin. Anyhow, the activities start after a kick off meeting during which the Design Project Manager (PMD) analyses the briefing deepening every single issue such as aesthetic characteristics and product constraints, and releases the briefing to the team.

The process tasks are described in details in the following. The main tasks, and input and output are shown in figure 3.

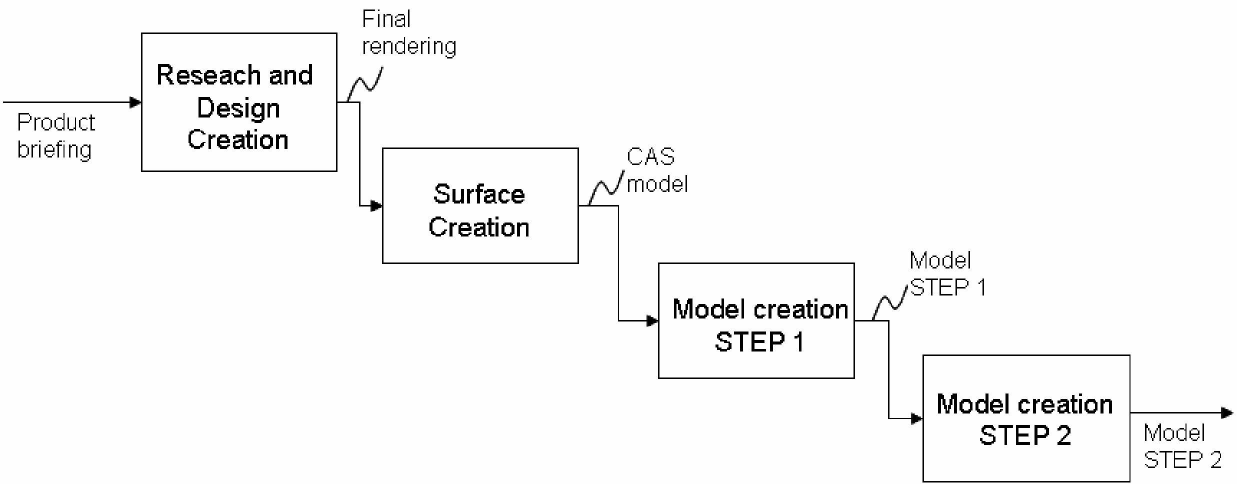


Figure 3. High-level tasks of Pininfarina product design process.

1) RESEACH AND DESIGN CREATION

This phase consists in planning and preparing, by means of studies and research activities, a fixed number of design solutions "in 2D", to be shown to the customer for approval.

INPUT:

Product briefing provided by customers
Team building

OUTPUT:

Final rendering

The sub-tasks of this activity are the following:

1. **Product meeting** - The aim is to inform Designers about customer’s expectations and methodological procedures;
2. **Preliminary sketches -** They show a preliminary design direction;
3. **Internal meeting -** The scope is to filter unfeasible proposals;

4. **Final Rendering -** Show a proposal that is described by fixed view (3/4 front-3/4 back-side);
5. **Photograph service -** Record and archive activities performed.

At the end of this phase the styling proposals are shown to the customer for evaluation and estimation; the presentation is normally customized on customer's requirements and closes either with the identification of a chosen solution, or with the request of a supplementary optimisation before the final assessment.

2) SURFACE CREATION

After the design intent has been identified and frozen, the process flow continues with the design objectification by means of Computer Aided Styling (CAS) activities.

During this phase concurrent engineering methodologies are applied: a 3D model is developed in parallel with the first engineering studies. Finally, the CAS model will be shown to the customer for validation.

INPUT:

Final rendering and engineering layout

OUTPUT:

CAS model

The sub-tasks of this activity are the following:

1. **CAS model** - The goal is to develop surfaces which describe the characteristics of the approved sketch integrating technical restrictions;
2. **check meeting –** it is checked if the original style intent has been preserved while keeping engineering constraints and finally input for NCM machine is released.
3. **CAS model modification** - Surface developed is upgraded following the check meeting.

3) MODEL CREATION STEP 1

An exterior "Step 1" model is a full scale model realized in soft resin. Gaps, headlight, taillight are represented as 2D decorations. Three-dimensional details such as handles doors, grills, wipers, badges and moldings are not included in the model.

On the contrary, an interior "Step 1" model is a painted model in scale 1:1, which simulates the final material. Details are represented only up to the belt line and are not three-dimensional.

During this phase, other engineering test are planned and performed simultaneously to the physical model development. Their aim is to guarantee the preservation of the vehicle architecture as well as the norms applicability and the packaging. The tests are carried on by engineers on surface scanned from the physical model.

INPUT:

CAS mathematical model

OUTPUT:

Model Step 1

The sub-tasks of this activity are the following:

1. **Creating mass material and milling machine path**
   These activities have the scope to transform the previous virtual model in a physical one.
2. **Smoothing and light paint**
   The model surfaces come out from the milling process need to be smoothed. Afterwards a neutral color is applied to the car body for a better shape evaluation.
3. **Macro Feasibility study**
   Ensuring the respect of the car architecture and normative constrains.
4. **Check meeting**

The scope is to check the physical model from both an aesthetical and technical point of view. If necessary, modifications will be carried out before showing the model to the customer.

5. **Modification phase**
   This activity has the scope to finalize the physical model on the basis of what has been discussed during the check meeting.
6. **Design Review**
   Design review is an intermediate presentation to customers at the end of which the customers can approve the model or, eventually, ask for further modifications. Modifications re done manually on the PMU, and require subsequent RE activities for reconstructing the digital model.
7. **Model scanning**
   A point cloud on the model shell is captured in order to reconstruct digital surface and subsequently either updating the CAS model or performing engineering tests.
8. **Paint and decorations**
   The task consists of model painting and gaps description by tape decorations.
9. **Photograph service**
   Performed activities are recorded and archived.

At the end of this phase, according to the previous plan, another customer presentation is organized for the final release.

4) MODEL CREATION STEP 2

INPUT:

Model Step 1

OUTPUT:

Model Step 2

The sub-tasks of this activity are the following:

1. **Scanning of the Phase 1 Model to update Mathematical model**
   This activity has the aim to update CAS mathematics after the physical modifications have been applied due to aesthetical optimization or feasibility verifications.
2. **Feasibility Studies**
   The aim of these activities is to guarantee the respect of the technical feasibility requests.
   The contents either of the CAS or Class B (*) as well as the scanning surface are verified thanks to a proper check list.
3. **Interior meeting verification**
   This activity has the aim to analyse the model Phase 2 in order to define the eventual modifications congruent with the presentation organised in the previous phase.
4. **Modification execution**
   This activity has the aim to refine the model according to what has been agreed during the interior meeting.
5. **Design Review**
   Design review is an intermediate presentation to customer at the end of which the customer can approve the model or, eventually, ask for further modifications.
6. **Symmetry**
   This activity consists in the double over the model
7. **Photograph service**
   According to the initial plan, a final presentation (interior/exterior) is organized for the customer for its evaluation and approval.

(*) <u>CLASS B DEFINITIONS</u>

- Definition with Bezier surfaces of the style model;
- Introduction of the technical contents in coherence with the feasibility studies;
- The style radius is comprised, but not the technological ones;
- The development of the inner completions is not included;

- It is considered the satisfaction of tangency (G1) criteria between the surfaces;
- The diagnosis of the curvature continuity (G2) between the surface ones is not included;
- The diagnosis of the reflection lights is not included;
- All the details like window moldings, side moldings, badge, etc. are not included;
- The mathematics can be used in order to obtain rapid prototyping/models;
- It is not possible to get mould using this mathematics.

Metrics

Typical parameters and aspects that are considered for evaluating Pininfarina design workflow are the following:

1. 4/5 sketch proposals are provided for each design;
2. For every proposal, provide 3 sketches (3/4 front-3/4 back-side);
3. A maximum of 2 CAS model or physical scale models made with clay are provided;
4. One full scale milling model is made using foam material;
5. Design and engineering review activities;
6. One full scale milling model is made using hard material.
7. Evaluation/modification activities occur trough all the design process

Analysis of critical aspects

In the design process the following critical points can be identified:

1. **FROM 2D TO 3D**
   Moving from a 2D sketch into a 3D model is for sure the most painful step in design process, where high skill and experience is requested.
2. **REVERSE ENGINEERING**
   When it is required to go back from real models to virtual models, the currently available technology (optical scan, point cloud or STL file, CAS or ‘automatic’ reverse engineering) allows a long and expensive process and does not guarantee high quality results.
3. **VISION**
   Transforming in 3D unclear design intent needs a huge amount of work and resources. It would be useful having a tool that do not help designers in concretize their ideas by enabling them to sketch in 3D.
4. **Communication within the project team**
   The iteration and harmonization of the 4 different process actors (stylist, modeler, engineer and PMD) may represent a critical issue to be addressed.

3.3.2. General expectations

How to improve the process

Once the critical point of the workflow has been identified, any action going in the direction to reduce the criticisms which may arise during the workflow is really welcomed and helpful.
In particular, regarding the transition from 2D to 3D the challenge for a tool could be to become a real alternative to the scale clay model.
In order to get this T’nD system must be as user friendly and efficient as the old process but with the additional possibility to have at the end a high quality surface definition.

3.3.3. Pininfarina requirements for T’nD

The expectations is to get a tool that on one side aids the designer to translate with greater facility and immediacy (in respect to today’s tools) the design intent; on the other side, T’nD mathematical output has to be used in real-time within the process.

3.4. Eiger

3.4.1. Design process at Eiger

Description of current design process

During the process of materialisation and planning from one idea to a product it is necessary to structure a development process. There are a lot of specialists, professionals and departments that will act during the process; they will develop different actions that will be related in a higher or lower grade. The departments with more presence will be Marketing, Engineering and product design. There are other departments, such as financial, quality, process engineering, logistics, and customers and suppliers. All will be done inside a context of concurrent engineering. Usually Eiger acts as an external design department, but with direct communication with the company.
The Industrial Design appears inside the product development process, and has an independent character, but it is integrated in the globality owned by product generation. We can’t isolate the Industrial Design process, because it is a media and not an objective, inside the context of product development, which has the priority of presenting new products to the market that incorporate value for the users, and consequently generate competitive advantages.

General characteristics

The Industrial Design process has a general structure that could be used for any kind of product, but will be differentiated by the following factors factors:

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

The process of industrial design incorporates different procedures, justified by the application of methodologies and concrete techniques, depending on the application of theoretical and empirical practices, as well as, in relation to the types of the specific professional activity.

The process has an iterative and heuristic character, appearing by a sequential way. This practice has been changing, for Eiger, approximately for one decade, as a result of the incorporation of new applied technologies, the evolution of graphical computer science, and the strategic competition. This situation has caused the introduction of practices of simultaneous engineering that allow carrying out activities in parallel instead of in series, and consequently reduces the time inverted in the development and diminishes the uncertainty and the risk. Also it facilitates a more and more fluid communication between the agents implied in the process.

<u>Process phases</u>

The process of industrial design will be divided in different chained phases, appearing at the end of each one of them decision nuclei where all the conducted activities converge. Non-sequential actions between inter-phases appear in any case.
The process is structured in phases, and has a general character that appears as follows:

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

All the phases have an internal procedure that is shown in Figure 4.

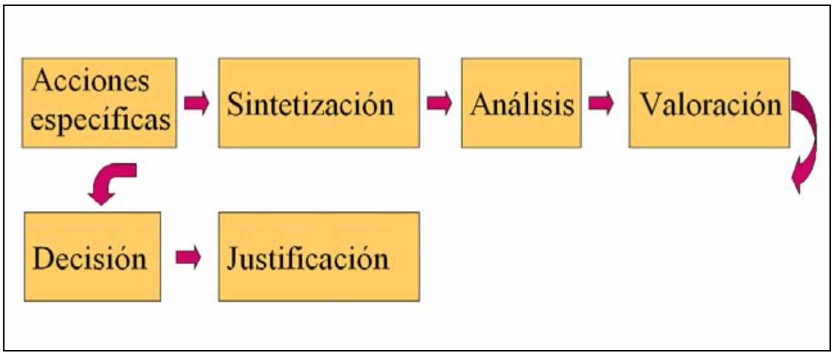


Figure 4. EIGER process including specific actions, synthesizing, analyse, valuation, decision and justification.

The design process forces to count, initially, with a product concept, defined by the area of marketing, and a basic specification with its application in the field of the industrial design. The specification considers the initial expositions defined by the departments; Finances, Engineering, Marketing, together with the supervision and the approval of the Staff, and reflect the strategy of the company and the specific product policy.

<u>Information and Analysis phase</u>
Inside that phase there is a study of different aspects related with:

- The antecedents of the own product and the competition.
- Study of market analyzing tendencies, segments, range and positioning.
- Formal and functional study.
- Ergonomics analysis with a special emphasis in the anthropometry and the relation with biomechanics.
- Analysis of use.
- Solutions of QFD.
- Collection of information of consumers, research centres, fairs and congresses.

At the end of the phase a report of conclusions will be emitted where the activity of product design to make in the later phase will be oriented, defining expositions that will be a referring.

<u>Concept definition and alternatives phase</u>
During this phase the possible concepts will be formed, with general character that give answer to the requirements specified in the specification and to its possible alternatives. A two minimum of and a maximum of five alternatives are developed.
The design requirements will study; aesthetic, form and functionality, ergonomics, use, jointly with the aspects of communication and the symbolic ones.
The own activities of this stage are:

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

In the last stage of the phase, the concepts and alternatives chosen with the recommendations or suggestions raised are used as datum points for the beginning of the following phase.
As supports to the proposal of alternatives are used:

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

Definitive alternative development phase

On the basis of the alternatives chosen in the previous phase we will advance in the definition of the design, specially for what concerns the aesthetic aspects (colour, texture and form), considering the recommendations of Product Engineering, emphasizing respect materials, processes, costs, and considering the necessary volumes for the location of internal technical elements, as well as its systems of subjection and assembly.
The following supports are made:

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

At the end of the phase the results and all the documentation will be analysed by Product Engineering department to avoid dysfunctions in the aspects which are interrelated with industrial design phases.

Industrialization and finalizing phase

In this phase the design activity is reduced to the possible modifications caused by the difficulty in the industrialization, produced by the materials, processes and assembly of the parts and components of the product. The test, test results will consider of laboratory, focused analysis of market in user groups. The valuation cannot be forgotten: it is made through series 0 and the preliminary series.
These modifications will be consequence of the analyses of the final documentation, especially of the validation of the prototypes, which are conventional, rapid prototyping, or functional models.
Also, during this phase package or packaging and the books of instructions can be developed.

The supports to this last phase are the followings:

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

The described process is a general base that can be subject to variations, according to the typology of the product, but that, as a rule, all the products will follow. Figure 5 shows some images of the same product (a vacuum cleaner) during the various design phases.

Figure 5. Example of products during the various phases.

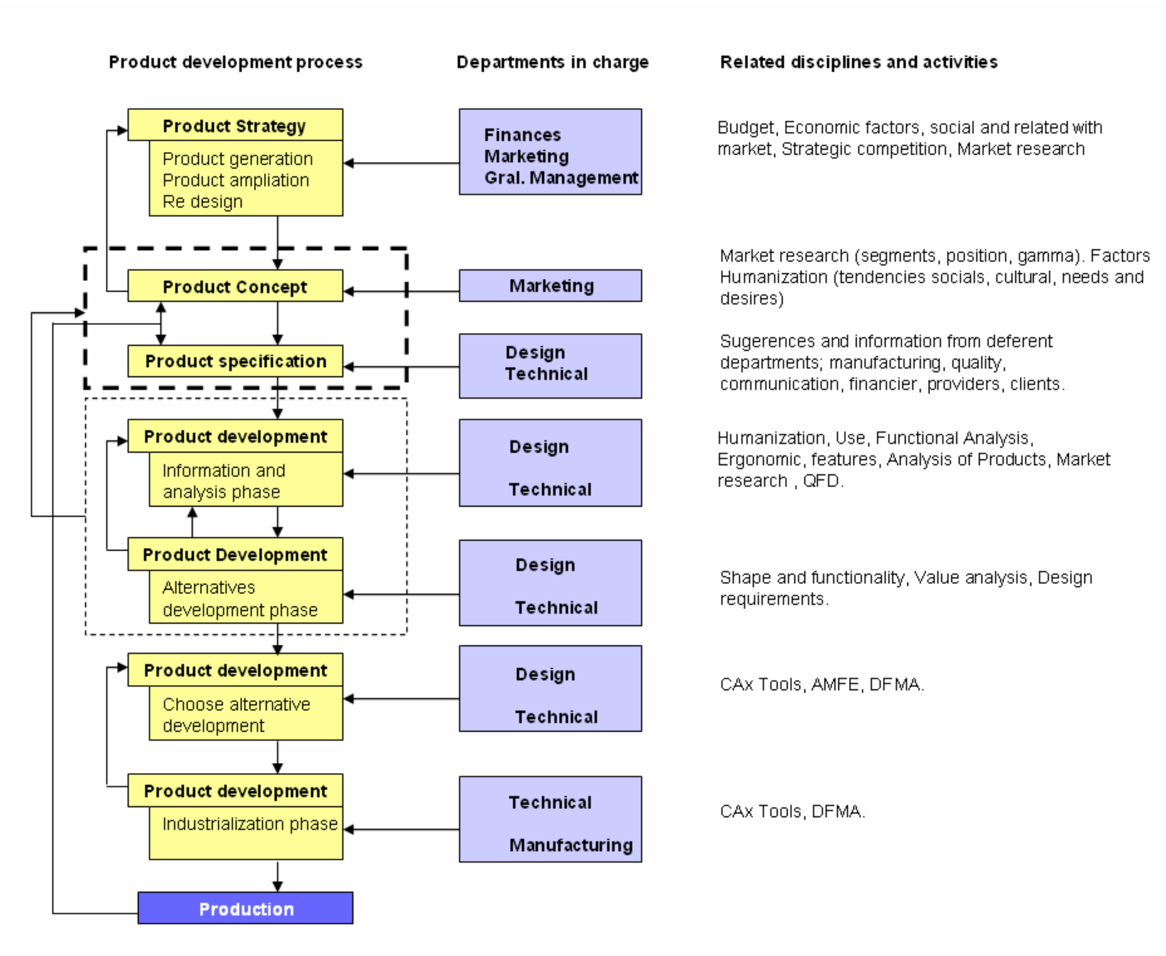


Figure 6. EIGER Design Process phases.

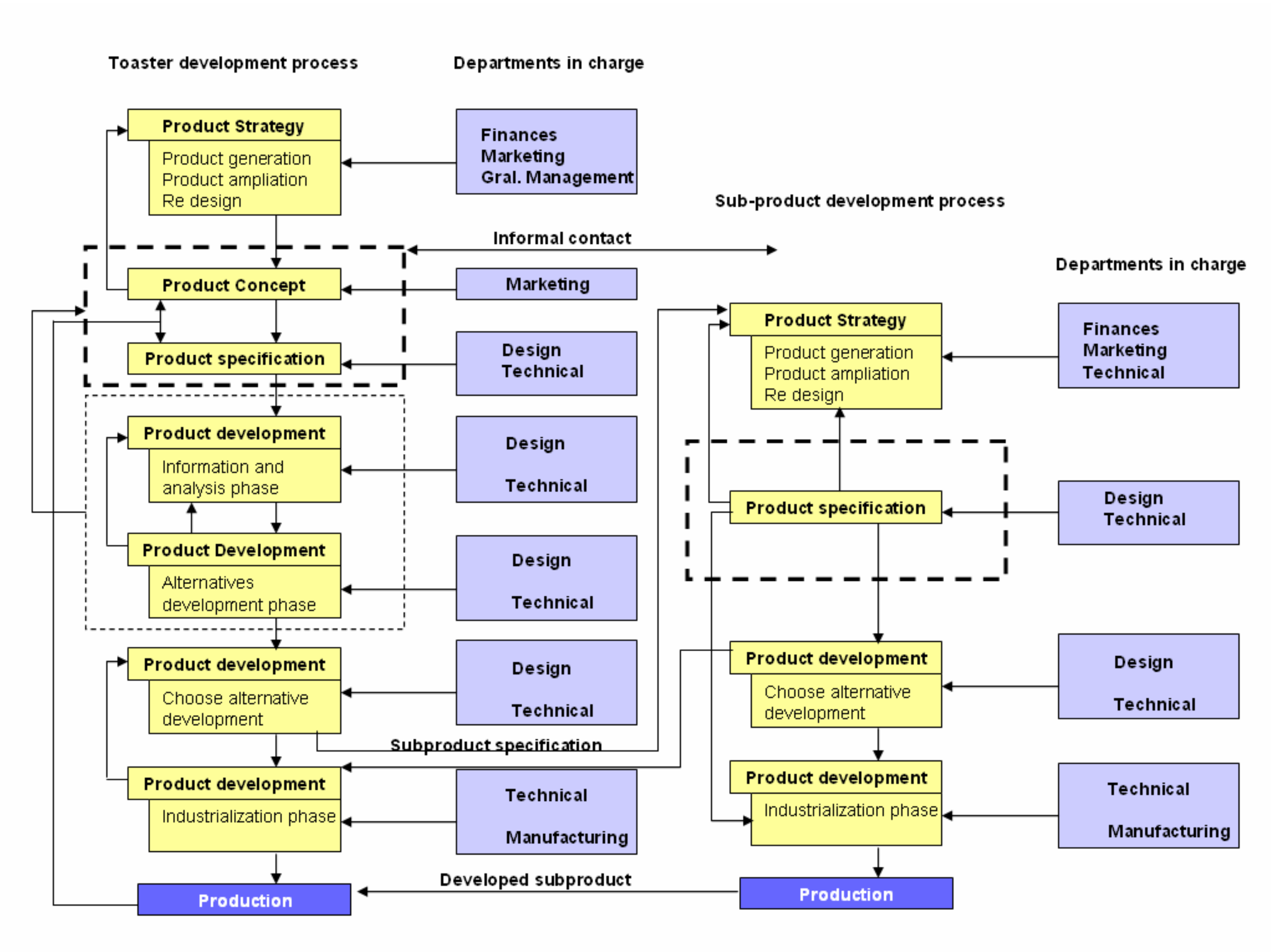


Figure 7. Design Process when working as sub-contractor or sub-contracted company

Metrics

In order to provide some parameters that can be used for evaluating the design process performances, we refer to one of our more recent projects:

- 5 designers create several sketches: 30 initial sketches, in 3 days.
- Designer selects few sketches: First trial 15 sketches, in 3 hours.
- Modellers create maquette out of sketche(s): 5 initial mock-ups, based on the sketches, in 5 hours.
- Evaluation/modification iterations: 3 to 4 iterations, including new sketches and models, in 2 weeks.
- 2 designers have produced CAS models, 9 models, in 3 days.

Analysis of critical aspects

Some critical tasks of process and tools are the following.

- critical aspects of the process
  - 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 contractor
- critical functions of the modeling technology
  - Sketching ability
  - 3D vision
  - Technical approach capabilities
  - 2D, 3D model to mock-up process

- critical usability aspects of the modeling technology
  - Must be friendly

3.4.2. General expectations

How to improve the process

It is evident that the best way to optimize and improve the project is avoiding iterations and returns to a theoretically finalized phase.
It is important to save time and save number of supports (sketches, mock-ups, models, …) used to define the product. Make the process more efficient and effective.

Expectations about technology

The expectations are always related with the fact that we will go faster developing projects, and the information delivered by the modeled product will be richer, in terms of vision and sensorial analyses.
We expect new work-flows where the knowledge and the ability will be linked and optimized by the use of new interfaces.

3.4.3. Eiger requirements for T'nD

- The system must be as friendly as possible.
- There must be ergonomical- anthropometrical analyses to make the system health and secure.
- The Designer must be comfortable with T'nD.
- The learning curve must be as small as possible.
- The number and complexity of surfaces that could be created with the tool must be sufficient to model almost a simple product or modify it.

3.5. Synthesis of users' As-Is Scenarios

This section makes a synthesis of the three end-users' design processes. Three scenarios, named *As-Is Scenarios*, depict the various product design processes. They differ for what concerns the activities, resources and tools used in the processes. The three scenarios are described in the following using schematic representations, and more technical IDEF0 diagrams.

<u>Scenario 1</u>

Three users are involved in the process: designer/stylist, modeler and engineer. The designer produces sketches, 2D renderings and 2D technical drawings for describing his ideas. Few of them are selected and given to the modeler who makes physical models (PM) out of them interpreting the sketches content. The modeler uses different materials to produce the prototype. For example, in Alessi the modeler uses malleable materials (like clay) for producing a model that is low quality, and uses more rigid materials (like resins) for producing higher quality models. Each physical model is then given back to the designer/stylist for validation and evaluation. The designer might require some modifications that are communicated to the modeler using informal and not codified input. The number of loops required for product style improvements might be several. The physical model is accepted by the designer when it reflects at best his initial design intent. At this point, the physical model is passed to the engineer for producing the CAD model. This last activity is frequently performed using Reverse Engineering (RE) techniques that allow the reconstruction of the object shape, or at least of the main shape features of the object (styling curves). The RE model is a faceted model, not precise, that require to be further elaborated in order to obtain high quality CAD surfaces (usually NURBS). Once the high quality virtual model is ready, it has to be tested in respect to initial designers' ideas regarding the product. This is often done by making a physical prototype out of the virtual model using some Rapid Prototyping (RP) techniques (stereolitography, LOM, multi jet printing, etc.) or CNC techniques, that allows designers to evaluate and check the final representation of the product. It is often the case that the RP model is

very close to the initial designer’s intent. Anyway, in case modifications are requested by the designer, they are not formally described with reference to the RP model, and have to be implemented into the CAD model, and tested again. This is a very critical issue that at the moment has not optimal solutions. The output of the overall activity is a CAD model that has been validated and accepted by the designer.
Figure 8 shows the users, their skill, the tools they use and the outputs they produce, and the activity flows. Figure 9 describes the process in a more technical fashion, using the IDEF0 technique.

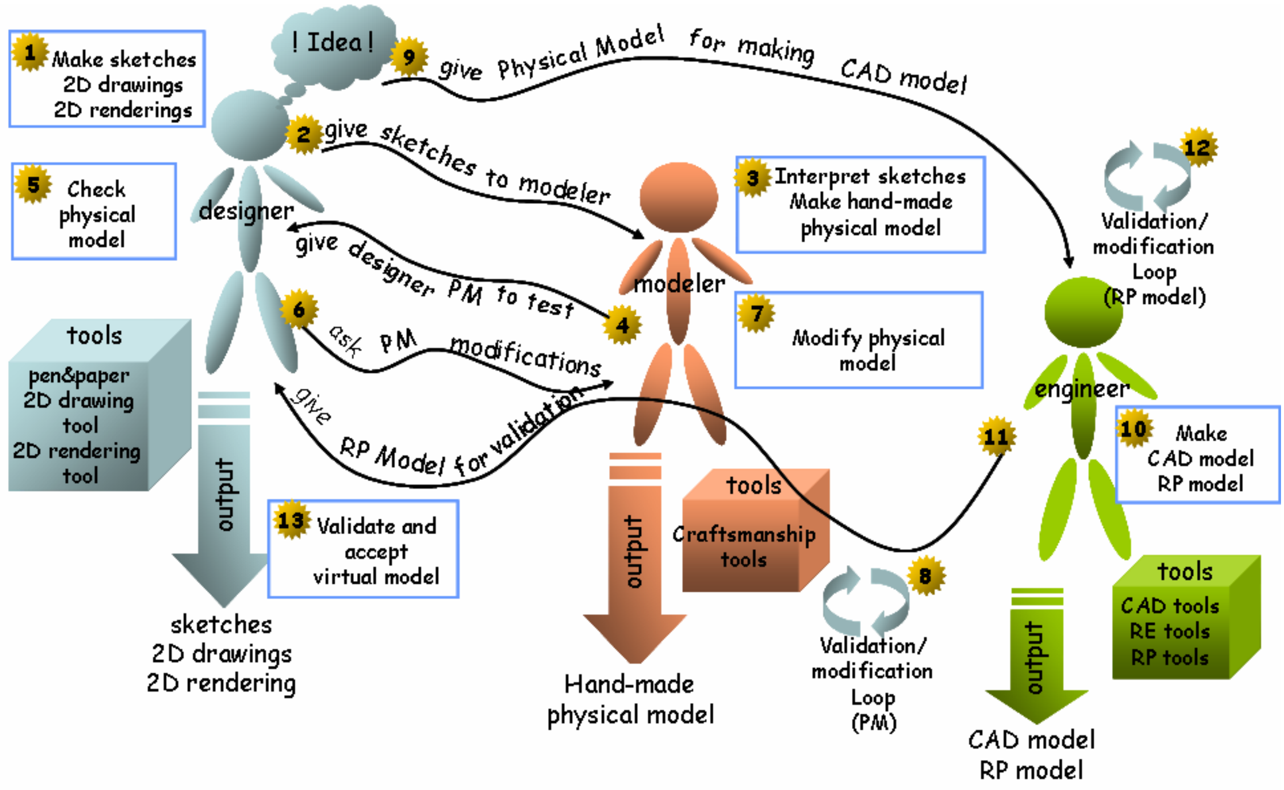


Figure 8. Schematic representation of As-Is Product Design for Scenario 1.

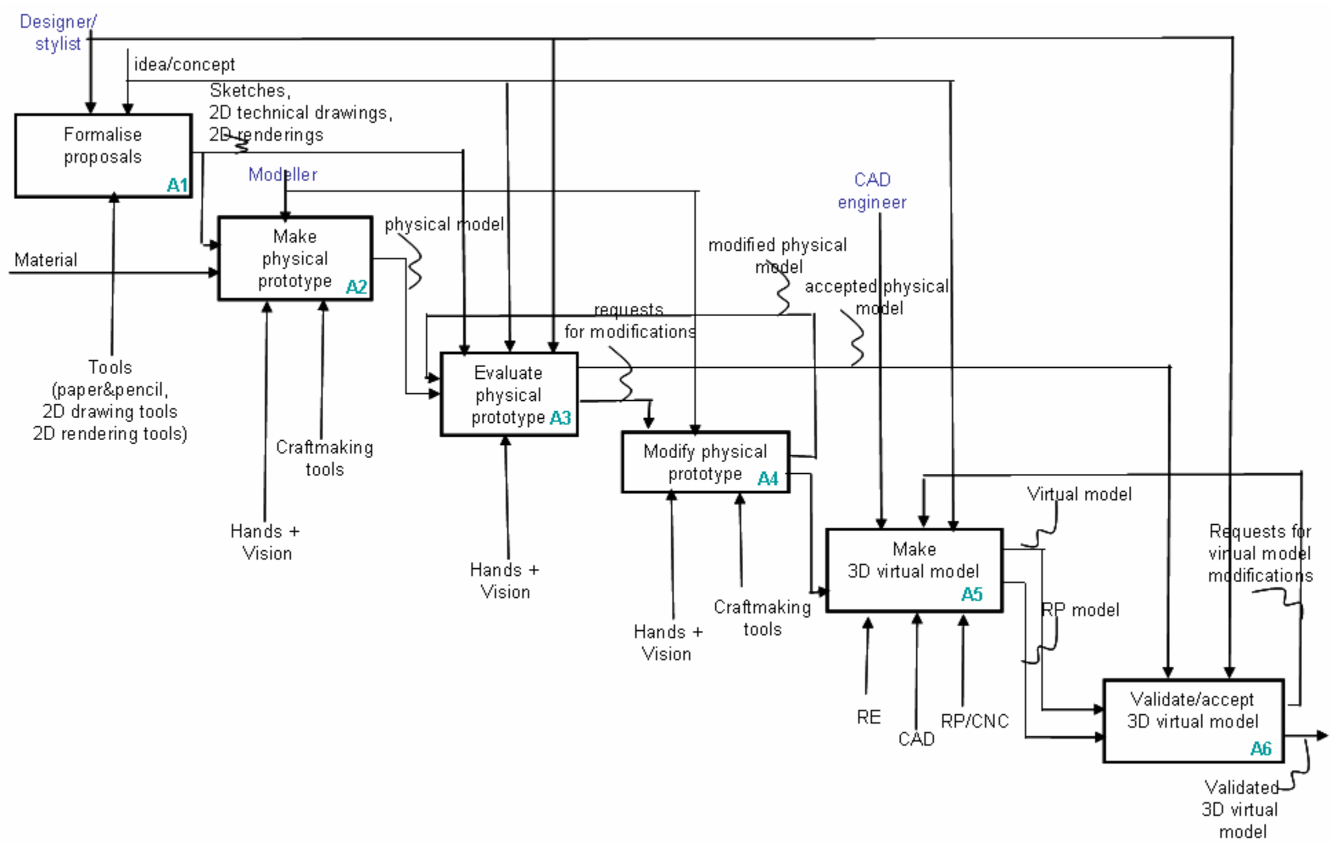


Figure 9. IDEF0 diagram describing the As-Is Product Design for Scenario 1.

The following critical issues are identified in the process:

- The designer makes several sketches and technical drawings representing his product concepts, but only a few are selected for physical prototyping. This does not allow designers to fully evaluate all their ideas, and sometimes the best ones might not be considered.
- There is cognitive load of the modeler since he is required to interpret the designer's sketches that most of the times are incomplete, ambiguous, and vague.
- The modeler's understanding of product concept through interpretation of designer's sketches is often subject to errors and misunderstandings that require several subsequent modifications.
- The physical model produced by hand is often of low quality (in particular those built using malleable materials), and therefore poorly represents the product.
- Requirements for styling modifications to implement onto the physical prototype are difficult to communicate, and are expressed in an informal and not codified way.
- Modification loops for style improvement required for obtaining a description of the product that is as close as possible to the initially intended one might be several (for example, at Alessi they might be 6-10).
- Modification loops often cause delays, since the evaluation and modification activities are performed by different actors.
- The physical modeling phase requires a subsequent Reverse Engineering phase for obtaining the CAD model of the product. This requires time and is error prone. Besides, the RE model is a faceted model, not precise, that requires being further elaborated in order to obtain high quality surfaces necessary for subsequent analysis and production phases.
- The designer has to check the virtual model made by the engineer using a CAD tool. This often requires another physical prototyping phase (RP) where the product is built physically starting from CAD data and given to the designer for testing.
- Requirements for styling modifications to implement onto the physical prototype are again difficult to communicate, and are expressed in an informal and not codified way.

- Practices for importing and implementing requests for shape modifications done on the RP model into the digital model are not consolidated yet, and often require the use of RE techniques.
- Modification loops for style improvement required for obtaining the final product representation might be several.
- Physical models and sketches, technical drawings, and pictures do not necessarily represent the same object at the end of the styling activities.

Scenario 2
Two users are involved in the process: designer/stylist and engineer. The designer produces sketches, 2D renderings, 2D technical drawings and physical models for describing his ideas. The physical model is directly evaluated and modified if necessary by the designer himself in order to satisfy at best the design concepts. Once the physical model satisfies design concepts, it is passed to the engineer for producing the CAD model. This activity is frequently performed using Reverse Engineering techniques. Once the CAD model is produced, it has to be tested in respect to initial designers' ideas concerning the product. This is often done by making a physical prototype using a Rapid Prototyping or CNC techniques that allows designers to evaluate and check the final representation of the product. It is often the case that the RP model is very close to the initial designer's intent. Anyway, in case modifications are requested by the designer, they are not formally described with reference to the RP model, and have to be implemented into the CAD model, and tested again. This is a very critical issue that at the moment has not optimal solutions. It often happens that RE activities have to be performed in order to acquire modifications made on the physical model, and consequently update the CAD model. The output of the overall activity is a CAD model that is validated and accepted by the designer.
Figure 10 shows the users, their skill, the tools they use and the outputs they produce, and the activity flows. Figure 11 describes the process using the IDEF0 technique.

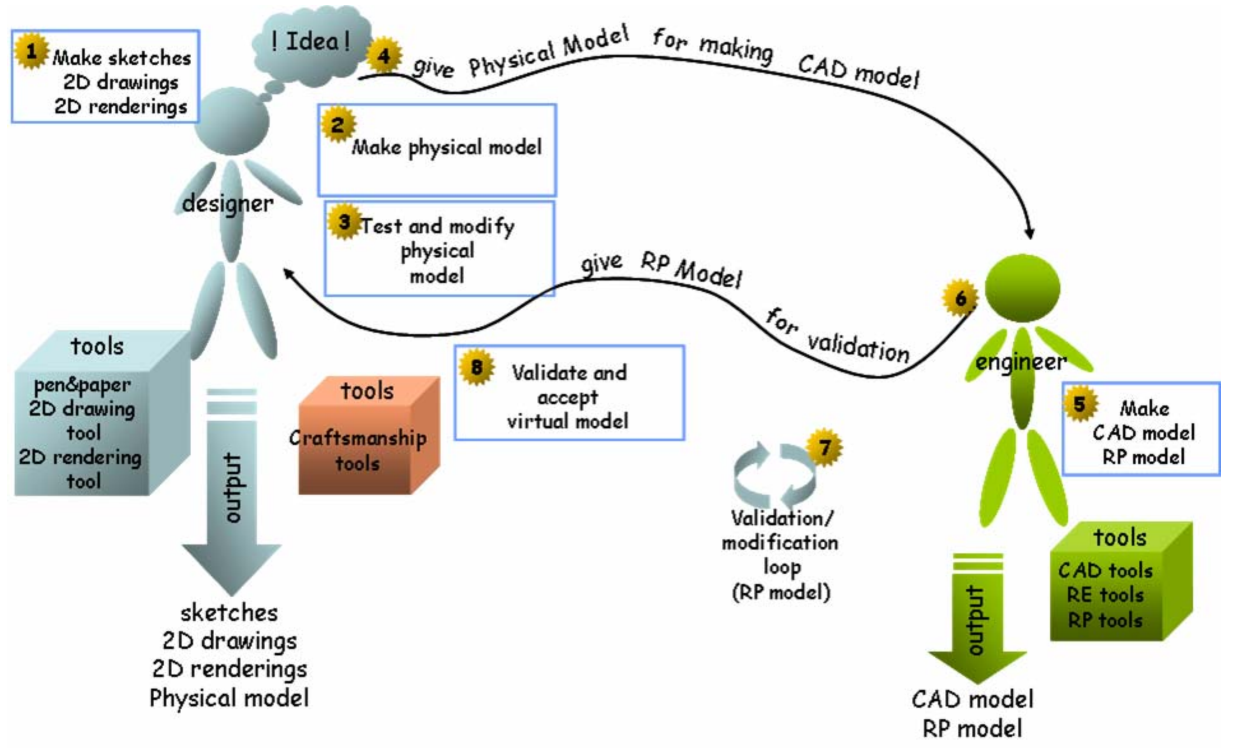


Figure 10. Schematic representation of As-Is Product Design for Scenario 2.

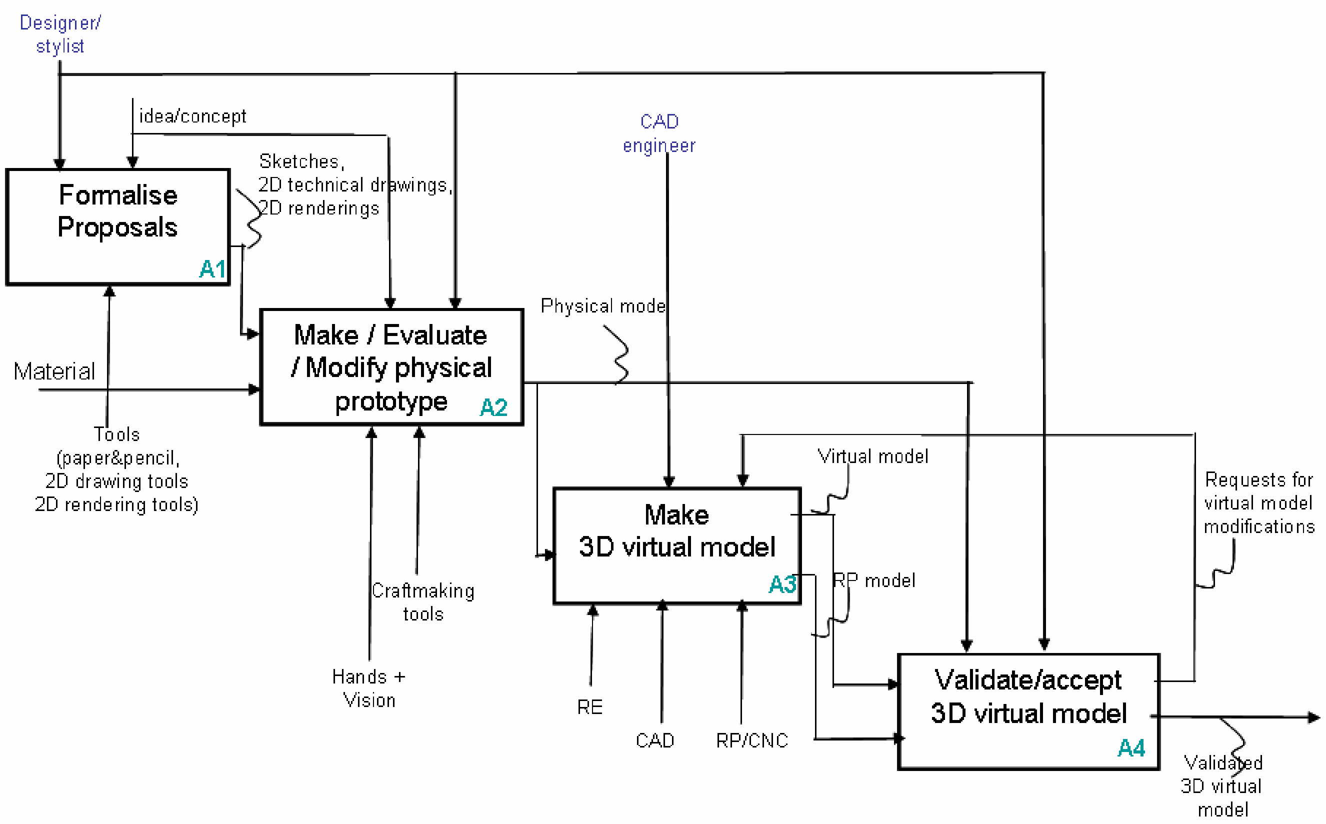


Figure 11. IDEF0 diagram describing the As-Is Product Design for Scenario 2.

The following critical issues are identified in the process:

- The designer makes several sketches and technical drawings representing his product concepts, but only a few are selected for physical prototyping. This does not allow designers to fully evaluate all their ideas, and sometimes the best ones might not be considered.
- The physical model produced by hand is often low quality (in particular those built using malleable materials), and therefore poorly represents the product.
- Even if in respect to Scenario 1 there is not the problem of interpreting sketches by modeler, activity that is subject to errors and misunderstanding, there is anyway the problem that designers and engineers speak different languages, and therefore the communication and comprehension is not always straightforward.
- The physical modeling phase requires a subsequent Reverse Engineering phase for obtaining the CAD model of the product. This requires time and is error prone. The RE model is a faceted model, not precise, that requires to be further elaborated in order to obtain high quality surfaces necessary for subsequent analysis and production phases.
- The designer has to check the virtual model made by the engineer using a CAD tool. This often requires another physical prototyping phase (RP) where the product is built physically and given to the designer for testing.
- Requirements for styling modifications to implement onto the physical prototype are again difficult to communicate, and are expressed in an informal and not codified way.
- Practices for importing and implementing requests for shape modifications done on the RP model into the digital model are not consolidated yet, and often require the use of RE techniques.
- Modification loops for style improvement required for obtaining the final product representation might be several.
- Physical models and sketches, technical drawings, pictures do not necessarily represent the same object at the end of the styling activity.

Pros in respect to Scenario 1:

- There is no cognitive load of the modeler related to interpreting the sketches.
- No errors happen related to modeler's understanding of product concept through interpretation of designer's sketches.
- No modification loops for style improvement are required to be carried out on the hand-made prototype.
- No issues related to communication of requirements for styling modifications of hand made prototypes are present.
- No delays related to evaluation/modification loop regarding a hand-made physical prototype are present.

Scenario 3

Two users are involved in the process: designer/stylist and engineer. The designer produces sketches, 2D renderings and 2D technical drawings for describing his ideas. In addition, he produces a CAS model representing the product. Some variants of the product may be evaluated and tested through the product virtual model. Once the product model satisfies the design concepts, it is passed to the engineer for detailing the CAD model. This phase requires the reconstruction of high quality surfaces from low quality CAS surfaces. This activity is frequently followed by Rapid Prototyping or CNC phases for realizing a physical prototype of the product, directly from the CAD model. The physical prototype is used by designers to evaluate and check the final representation of the product. It is often the case that the RP model is very close to the initial designer's intent. Anyway, in case modifications are required by the designer, they are not formally described with reference to the RP model, and have to be implemented into the CAD model, and tested again. This is a very critical issue that at the moment has not optimal solutions. It often happens that RE activities have to be performed in order to acquire modifications made on the physical model, and consequently update the CAD model. The output of the overall activity is a CAD model that is validated and accepted by the designer.
Figure 12 shows the users, their skill, the tools they use and the outputs they produce, and the activity flows. Figure 13 describes the process using the IDEF0 technique.

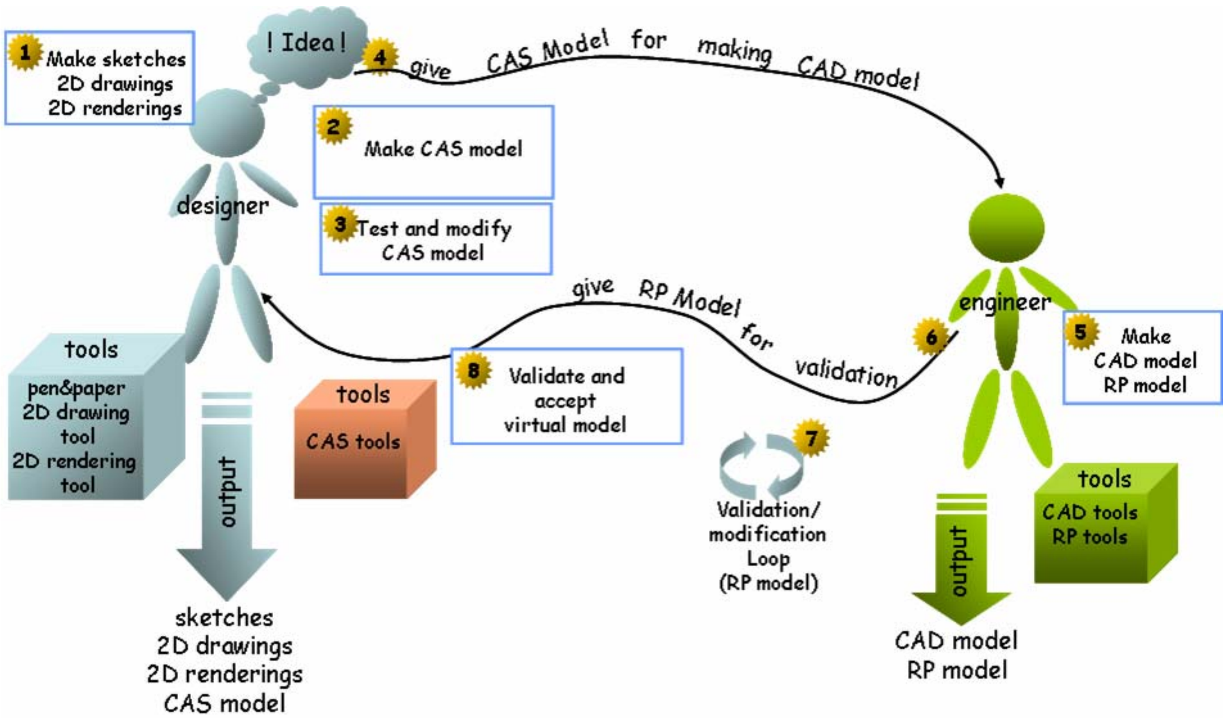


Figure 12. Schematic representation of As-Is Product Design for Scenario 3.

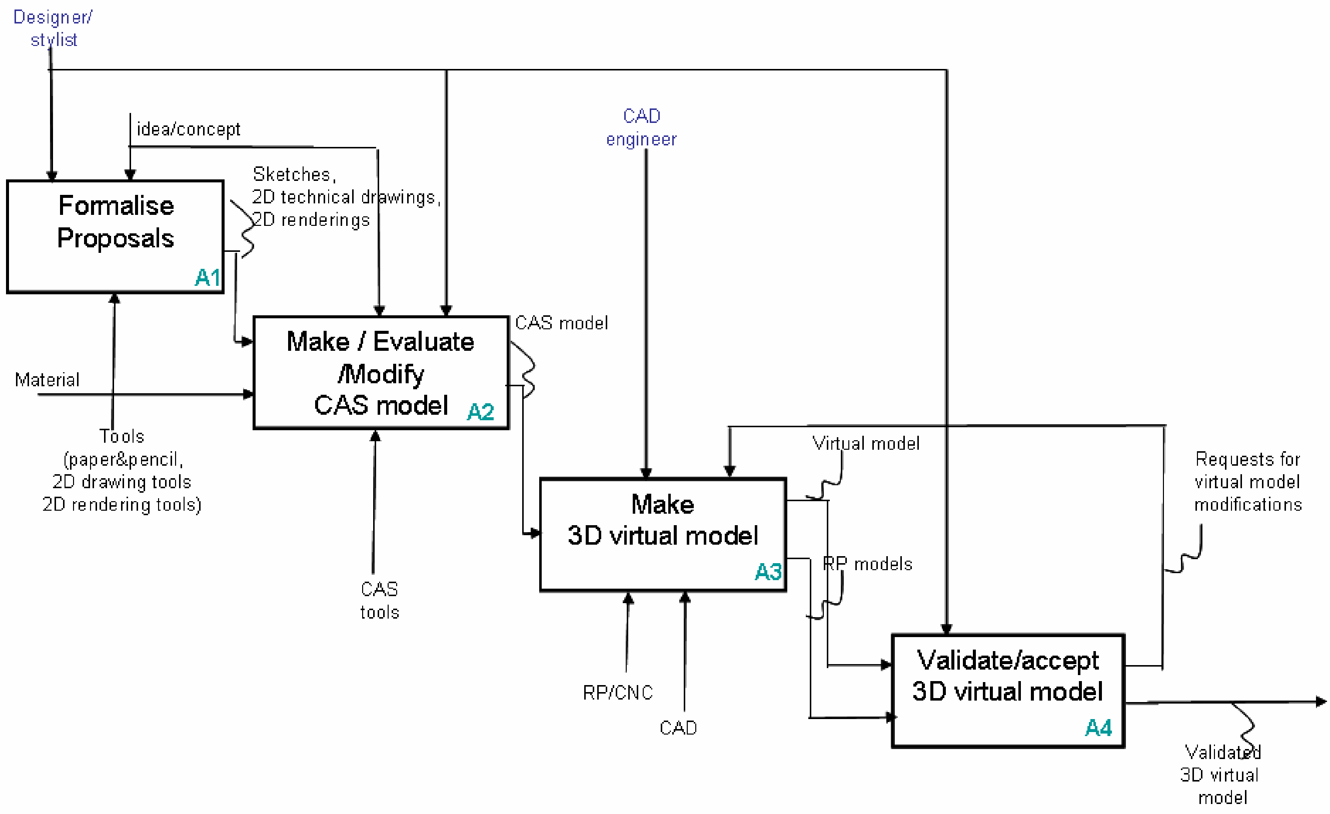


Figure 13. IDEF0 diagram describing the As-Is Product Design for Scenario 3.

The following critical issues are identified in the process:

- Not many designers are used to, or are willing to use CAS modeling for representing their ideas.
- It is not always the case that this is the best way of thinking of a new product.
- Several CAS tools use “mesh” representation that is low quality, and require to be translated into high quality surfaces. Surface reconstruction is often critical and producing errors and inaccuracy in surface reconstruction.
- The final evaluation is made using the RP model. There is no constant evaluation of design intent during the process.
- Practices for importing and implementing requests for shape modifications done on the RP model into the digital model are not consolidated yet, and often require the use of RE techniques.

Pros in respect to Scenario 1 and 2:

- No extensive use of Reverse Engineering is required.
- No hand-made physical model is made.
- RP is less expensive than hand-made prototyping.
- CAS and CAD models are almost coherent (apart from quality of surface representation).

Tables 1 and 2 summarize the three scenarios described, showing 1) the types of users involved in the design phases and the various types of output (documents, artifacts) they produce; 2) the tools used in the various design phases and the output (documents, artifacts) provided.
Table 1 summarizes the various types of users and the types of output created by each of them. As it can be seen, in the conceptual phase of design -that is the one addressed by the T’nD project-, several types of documents and artifacts are produced for representing, describing and communicating the design concepts and details: sketches, technical drawings, 2D renderings, CAS/CAD models, hand-made models, etc. The table shows that the various users in the three considered Scenarios have skills and competences to produce some of the listed outputs.

	Scenario 1			Scenario 2			Scenario 3		
	Designer	Modeller	Engineer	Designer	Modeller	Engineer	Designer	Modeller	Engineer
Sketch									
2D rendering									
2D technical drawing									
CAS model									
Hand-made prototype									
RE model									
CAD model									
RP/CNC model									
DMU									
Virtual Prototype									

Table 1. – Types of users and types of output

Table 2 shows the tools used in the various design phases and the output produced.

	2D hand made	2D paint	2D CAD	3D CAS	3D mesh model	3D CAD surfaces	3D CAD solid	3D CAD assembly	Multimodel (physics-based	3D hand-made	Physical model
Sketch											
2D rendering											
2D technical drawing											
CAS model											
Hand-made prototype											
RE model											
CAD model											
RP/CNC model											
DMU											
Virtual Prototype											

Table 2. – Types of output and types of tools used to produce them

In conclusion, from the synthesis of end-users' processes, we can say that Scenario 3 is the most efficient process compared to the other two. Anyway, it does not offer the possibility to constantly evaluate the design intent during the whole design process, since some aspects (like ergonomics aspects) still require physical models to be properly performed. Besides, some physical prototypes are anyway required at the end of the conceptual design process, in order to evaluate their correspondence with the initial design intent.

3.6. User's requirements

The analysis of the product development processes and tools conducted with end users has pointed out a list of needs and requirements for improving the process and for making technology better in terms of functionality and usability.

The users' requirements (**UR**) *for improving the process performances* are listed in the following. They are derived from the critical aspects of the design process listed in § 3.5.

- Design solutions that can be tested are limited; a lot of design opportunities are missing because only few initial ideas can be further developed mainly due to time required for making physical models.
    - **UR1:** Users require that the *number and complexity of design solutions* that can be tested is improved.
- The total time required to produce a satisfactory final product model is too high. This is basically due to the fact that the number of iterations of requests for style changes and modifications performed over the product models are too many, and the time occurring between the request for modification done by the designer and the actual modification performed by the modeler over the physical prototype might be high and causing delays.
    - **UR2:** Users require that the *number of activities and time* required for producing models *is reduced*, that evaluation/modification loops are improved making evaluation/modification activities easier and more direct, and that the delay between activities is diminished or eliminated.
- Hand-made physical models are expensive, take time and require skilled operators.
    - **UR3:** Users require that the *practice of producing hand-made physical models is improved* by providing tools/practices able to substitute physical modeling and reducing and/or eliminating evaluation/modification loops using physical prototypes.
- Model reconstruction and exchange (such as from CAS to CAD model, from physical prototype to Reverse Engineering to CAS model) is tedious, error prone and require time and expertise. In particular, RE is an expensive practice that should be avoided.
    - **UR4:** Users require that *model reconstruction and exchange*, and the use *of RE are limited* and used only few times when strictly necessary.
- Rapid Prototyping models are expensive (even if less than hand-made ones), are difficult to modify and re-align with CAD models.
    - **UR5:** Users would like that the *number of RP models is reduced* possibly to only one built at the end of the process, or that no RP models are necessary at all.
- The resources (users) required to produce the models are several and require to collaborate tightly -that is not always the case- in order to guarantee satisfactory results.
    - **UR6:** The users would like systems supporting the conceptual design activities that can be used by the *same person* also for performing very different activities.
- Several tools are necessary in the various phases of the product development process (from conceptual to marketing phase), requiring several users with appropriate expertise working in the product development phases, and causing several problems in data exchange.
    - **UR7:** Users require the possibility to use *few or a unique system* in the various phases (conceptual design phase, testing/evaluation phase, ergonomics studies, marketing) of the design process of a product.

- Virtual models and hand-made physical models are distinct, and not coherent between them.
    - **UR8:** Users require that *coherence between virtual and physical prototype* is guaranteed and assured in a more efficient and effective way in order to avoid errors, misunderstandings and time spent in model reconstruction and data exchange.

The users’ requirements (**UR**) for *improving the technology functionality and usability* are described in the following.
We investigate the features a system has to offer addressing three types of users:

- Stylists/designers who are skilled in making sketches, 2D technical drawings, and 2D renderings;
- Modelers who are skilled in using hands for creating shape, but who do not use digital tools;
- Stylists/designers who are skilled in using CAS/CAD tools but do not have expertise in hand making prototypes.

The three types of users express different requirements according to their skills and the tools they are used to use.

- Designers do not often model in 3D, and they prefer drawing in 2D. Therefore, other their product concept is vaguely represented; no virtual model is produced and is readily and immediately usable. Besides, designers show the desire to be able to construct 3D physical models to immediately see/validate in concrete their ideas, and to facilitate interactions with customers.
    - **UR9:** Users require easy to use tools, intuitive and user oriented, exploiting designers’ skill so as designers might be able to *produce, validate and modify virtual models*, without the necessity of having a modeler for making a physical prototype that they are able to evaluate.
- Modelers make hand-made prototypes starting from sketches made by designers. They have not the possibility to use digital tools and working directly in the digital phases of the design process since they do not have the proper skill for using those tools.
    - **UR10:** In order for modelers to use digital tools they are required to provide *working environment that resemble the one they use in their everyday activities*. Users require a working environment that is close to real workshop, and where tools for making objects are available and continuous tactile contact with the object is provided.
- Designers who use CAS/CAD tools point a set of major drawbacks of these tools that prevent them from using them extensively and on a regular basis:
    - tools are too technical, and more oriented to engineers than to creative people; thus, creative people, lacking the kind of technical training the engineers are given, spend an excessive amount of time trying to find out the appropriate procedures to reach the desired solutions.
        - **UR11:** Users require *easy to use tools* also for non expert CAD users, where functionalities are intuitive and easily reachable. Users want tools that allow them concentrating on their activities. They *do not want to be limited by, or care about technology*.
    - tools lack physical contact and continuous tactile feedback on objects that are being created.
        - **UR12:** Users require that tools also provide *tactile interaction* with the virtual model being built.
    - Conversely, designers point out some positive aspects of 3D modeling tools, they would like to preserve.

        - **UR13:** Users require that the system provide high quality *surfaces*, high quality surface check tools and quick modifications functions.
- Users would be able to create, modify and evaluate shapes using a unique integrated environment.
        - **UR14:** Users require using a unique environment for the creation, modification and evaluation of products.

4. T'nD process and system requirements

4.1. T'nD users and design actions

T'nD addresses two types of users:

- *Users 1* who are modelers skilled in using hands for creating/modifying shapes, but who are not able to use digital tools.
- *Users 2* who are designers/stylists skilled in using CAS/CAD tools but do not have expertise in hand making prototypes.

From WP2 – Users' skill capture and analysis, it comes out that the most typical actions performed by modelers making hand-made prototypes are the following:

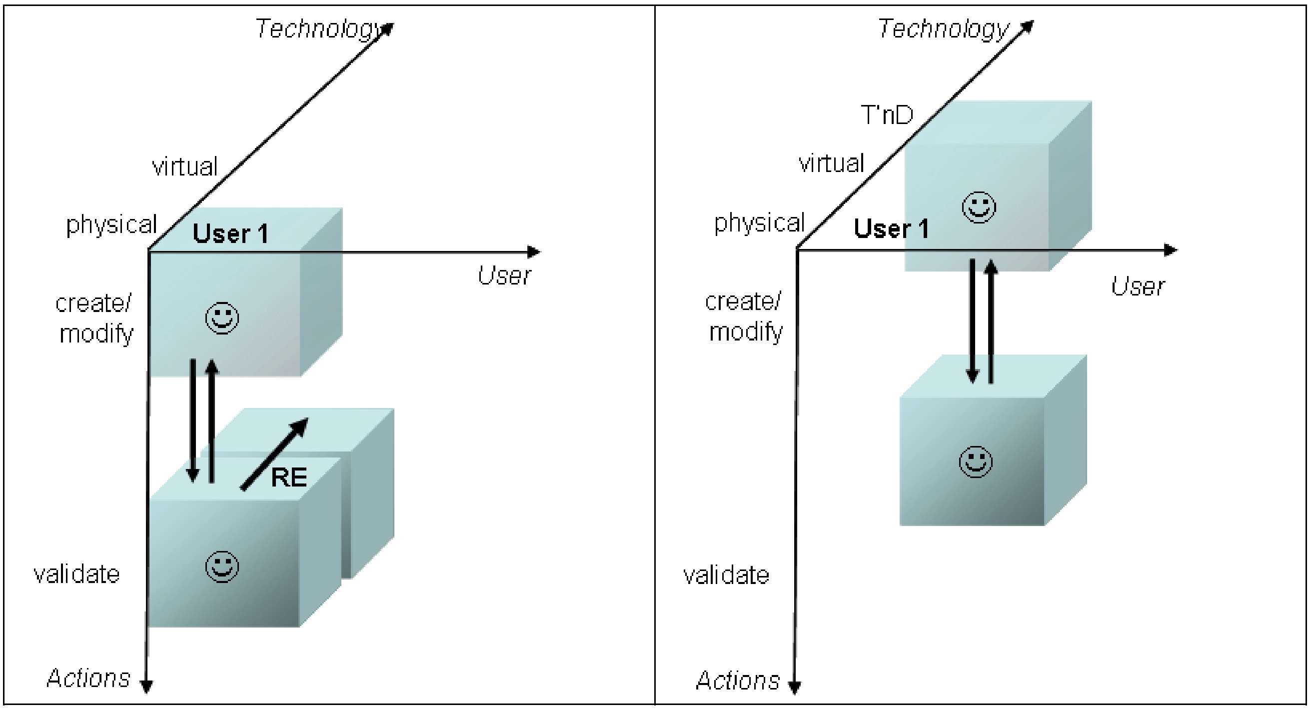
- *Create and modify* physical shapes by means of craftsmanship tools used for sculpting, finishing, smoothing the surface;
- *Evaluate/validate* object shape by means of hand gestures and hand motions used for touching the object surface.

Figure 14 shows a diagram representing the relations among types of users, types of technology and types of actions.

User 1 operates in the physical context for creating, modifying and validating the object shape. He requires an engineer to make a digital model out of physical model (often done using RE techniques).

User 2 operates in the digital context, where the object shape is created. The validation phase requires the manufacturing of a physical model that has to be made by technical people usually using RP techniques.

T'nD aims at providing an environment for both designers and modelers offering both physical and virtual functionality for the creation/modification and validation of product shapes within a unique system. The physical model is the immediate result of virtual modeling.



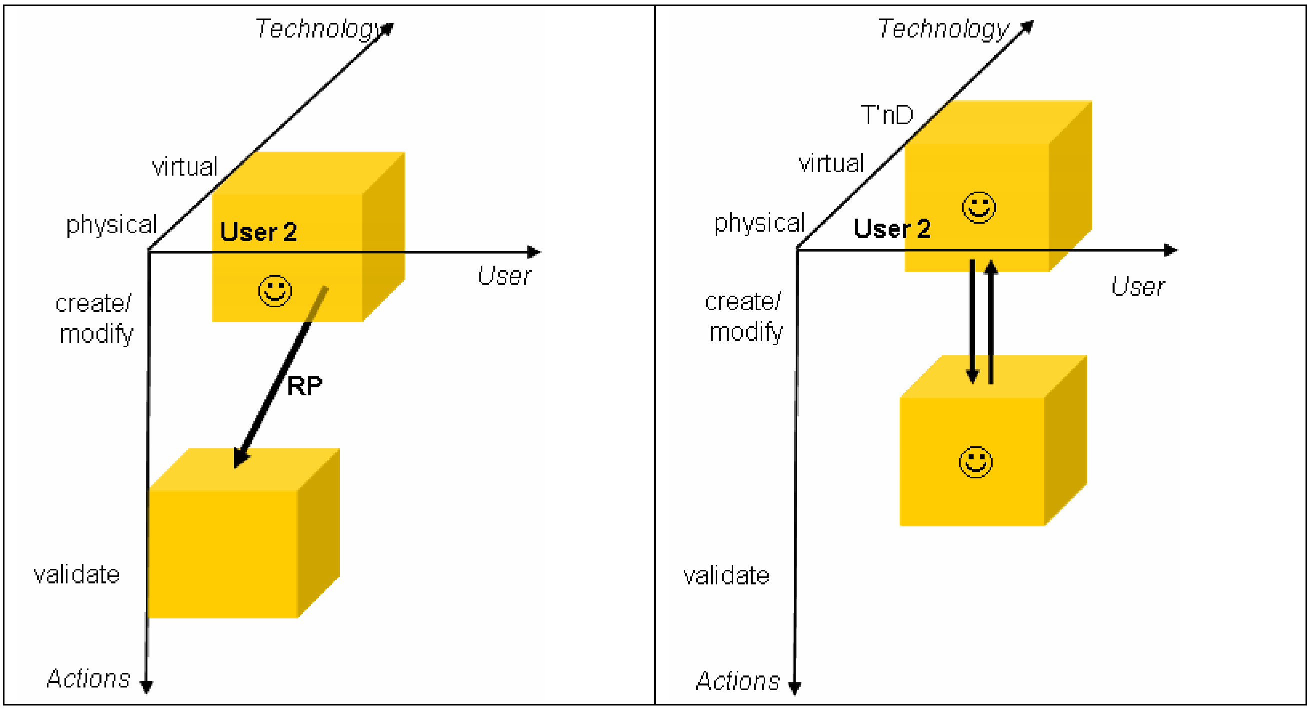


Figure 14. Users, actions and technology.

4.2. T'nD process

Starting from the requirements for process improvements, some new product design processes might be proposed. One possible improved design process that is going to be achieved by the T'nD system is described hereafter, and is shown in the following schematic representation (Figure 15) and IDEF0 diagram (Figure 16).

The main features of the T'nD process are the following:

- Design and testing activities are carried out in one *unique task*, performed by a *single user* (designer/modeler), using the innovative T'nD system.
    - In the laps of time available more design solutions can be evaluated (UR1).
    - The user makes a first version of the product, starting from his concepts and ideas, and can continuously and directly test and modify it. The model is created, tested and modified by the same user. Therefore, delays among the activities performance are reduced or completely eliminated, and the number of loops is also reduced (UR2).
- T'nD system provides a unique environment where physical and virtual (high quality) model can be constructed and validated.
    - The system provides and environment for making hand-made prototyping and virtual prototyping (UR3).
    - The output is a virtual/physical model that is represented by high quality surfaces (UR4).
    - No surface reconstruction or RE techniques are required (UR4).
    - Same user is able to develop product concept, virtual and physical model (UR6).
    - Tool used for creating an evaluated high quality representation of the product is unique (UR7).

  - o The product model developed using the T'nD system is unique and coherent: it is at the same time a virtual and physical model (UR8).

- The CAD engineer intervenes only at the end of the process, using the available CAD model that is provided by T'nD system in a high quality format, for refining and detailing the CAD model, and for making only few or even better only one final version of physical prototype of the product using a RP technique.
  - o The data exchange from CAS to CAD model is not required any more, since the designer is expected to directly produce a CAD model (UR4).
  - o The reconstruction of CAD model out of physical model using expensive RE techniques is not required any more (UR4).

- Since the design is validated at the beginning of the conceptual activity using its virtual and physical (haptic) representation, there should be no need to build several RP physical prototypes at the and of the design phase, but only very few or even just one might be necessary (UR5).

Figure 17 shows the way how the Scenario 3, which currently represents the best process, is improved by T'nD. In respect to As-Is scenarios, T'nD process offers the following benefits:
- the necessity to use RE techniques is limited;
- validation of virtual model is done by looking at it and by touching it. The final output is very close to the ideal product;
- less loops evaluation/modification of the RP model are required;
- high quality surfaces (instead of low RE or CAS models) are passed to the engineer for refinement and detailing of the CAD model;
- less RP models are required.

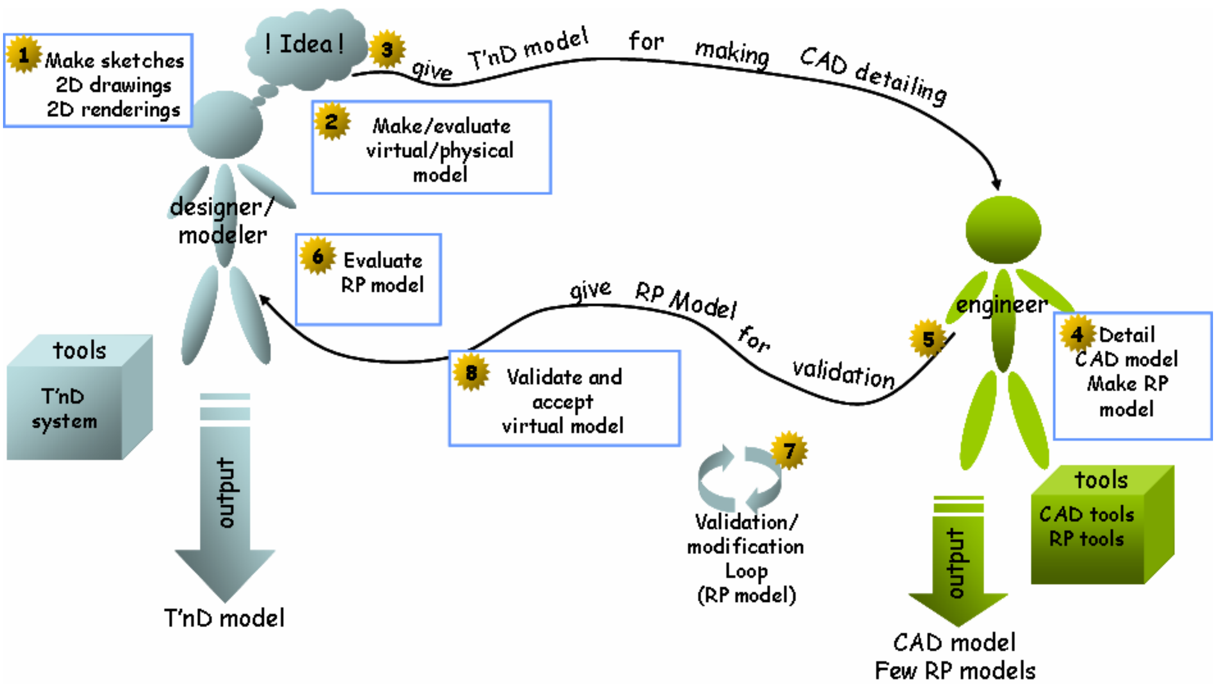


Figure 15. Schematic representation of Product Design process using T'nD system.

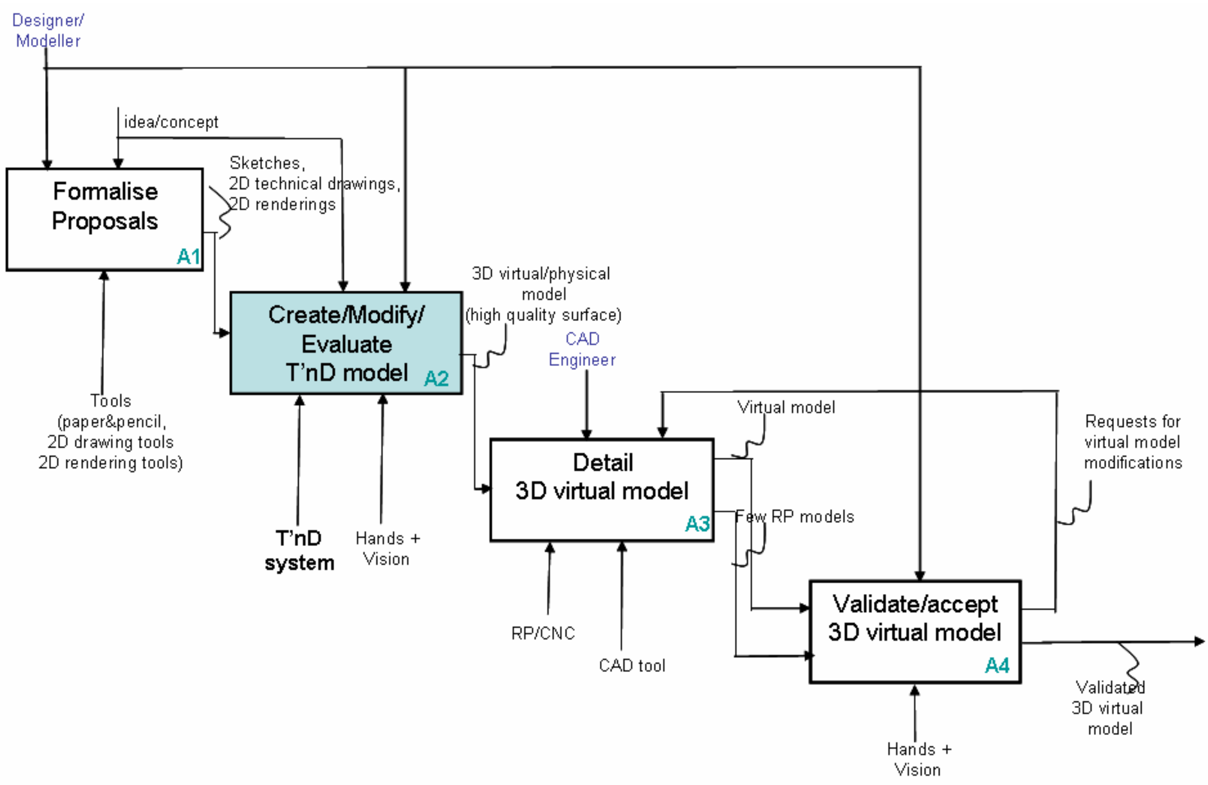


Figure 16. IDEF0 diagram describing the new T'nD process.

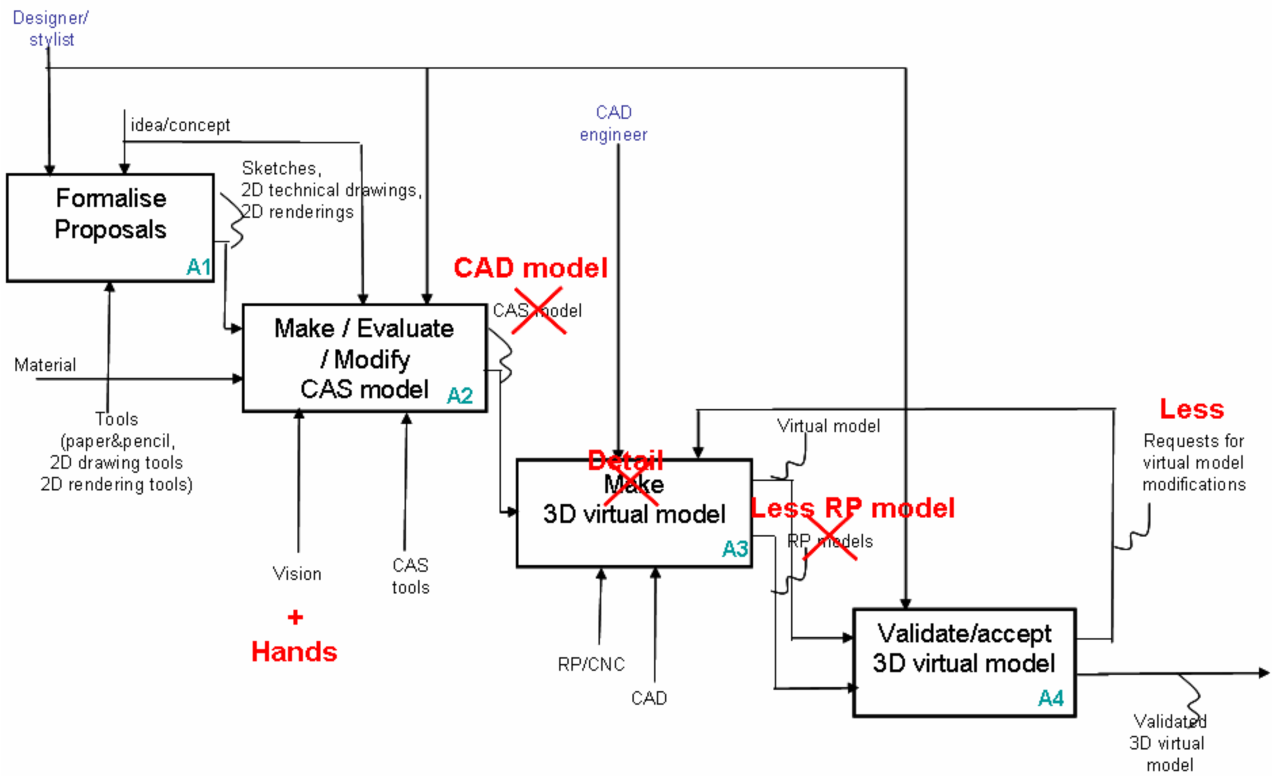


Figure 17. IDEF0 diagram showing the improvements of the T'nD process compared to Scenario3.

Tables 3 and 4 show the various types of users involved in the design phases and the various types of output they produce, and the tools used in the various design phases and the related output provided, in the new T'nD process.

	Scenario 1			Scenario 2			Scenario 3			**T'nD**	
	Designer	Modeller	Engineer	Designer	Modeller	Engineer	Designer	Modeller	Engineer	Designer/ Modeler	Engineer
Sketch											
2D rendering											
2D technical drawing											
CAS model											
Hand made prototype											
Physical/virtual model											
RE model											
CAD model											
RP/CNC model											
DMU											
Virtual Prototype											

Table 3. –Types of output using the T'nD system.

	2D hand made	2D paint	2D CAD	3D CAS	3D mesh model	3D CAD surfaces	3D CAD solid	3D CAD assembly	Multimodel (physics-based	3D hand-made	Physical model	**T'nD**
Sketch												
2D rendering												
2D technical drawing												
CAS model												
Hand-made prototype												
Physical/virtual model												
RE model												
CAD model												
RP/CNC model												
DMU												
Virtual Prototype												

Table 4. – Types of output and types of tools used to produce them.

4.3. T’nD system requirements

On the basis of the analysis of the critical aspects of current processes and tools, of the users’ requirements concerning technological issues, and of the proposed improved process, we can identify the following technological features that should be provided by the T’nD system.
T’nD should:

- provide and maintain a unique virtual and physical model (UR9).
- provide high quality output, and manageable surface that can immediately re-used (UR9).
- exploit as much as possible users’ skills (modelers’ skills). T’nD should build on hand-made virtual modeling approach, in a manner evocative of hand modeling (supporting some operations like scraping, rasping, polishing with sand paper, etc.) (UR10).
- allow designers to produce directly 3D models, starting from their ideas and concepts of products, in an easy and intuitive way, without any knowledge or competence on the use of CAS/CAD tools (UR11).
- provide continuous feedback on physical contact with the object being conceived (UR12).
- provide output that can be immediately used in the detailing phase performed using CAD tools by engineers (UR13).
- provide the possibility to re-use data: high quality output from design to engineering and vice versa (UR8, UR13).
- support easy and intuitive creation, modification and evaluation of product shape through surface generation by motion, surface quality check, etc. (UR14).

The following table summarizes the users’ requirements VS the process and system requirements that the T’nD system aims at satisfying, and the priority list.

Users’ requirements	Process/System requirements
UR1: More design solutions should be considered.	More design solutions can be considered in the given time since the phases are shortened.
UR2: Reduce total design time; evaluation/modification loops diminish, activities are more integrated, delay among activities diminishes.	Evaluation/modification activities are more integrated, and performed by a unique user; the number of iteration is reduced.
UR3: Improve practice of hand-made prototyping.	Hand-made prototyping is also producing a digital model.
UR4: Reduce use of model reconstruction, RE.	Output of T’nD system is a physical/virtual model, where the physical model is always the result of the virtual model. No surface reconstruction or RE techniques are required.
UR5: Reduce use of RP.	No need to build several RPs since the product concept is validated since the beginning.
UR6: A user should be able to perform various activities in the design process.	Same user can perform several activities.
UR7: Reduce number of tools used in the design process.	T’nD system is used for creation and evaluation of product concept.
UR8: Guarantee coherence among models.	T’nD output model is unique, and by definition coherent with the CAD model.
UR9: Tool offering modelers the possibility to make digital and physical models.	T’nD offers the possibility to create digital objects by “haptically” modeling them.
UR10: Tool supporting craftsmanship-like tools + continuous physical contact.	T’nD system provides surface creation operators based on hand motions that resemble the real ones.
UR11: Tool offering intuitive and easy-to-	T’nD system is so intuitive that also non-CAS/CAD

use functionality, not carrying about technology.	users are able to use it.
UR12: Tool providing tactile interaction with virtual models.	T'nD system provides haptic feedback of object surface.
UR13: Tool supporting the creation of high quality surfaces.	T'nD produces in output high quality class-A surfaces.
UR14: Tool supporting the creation, modification and evaluation of shapes.	T'nD system supports in a unique environment the possibility to create, modify and evaluate object shape.

4.4. Long-term T'nD system process

The T'nD process presented in the previous sections is a first step that the project aims at implementing for improving the current process and overcoming some critical aspects. Considering a more long-term vision, the design process might be further shortened and improved for example by eliminating the necessity to produce RP physical prototypes at the end of the conceptual design phase for product design validation. In fact, this might be done using the haptic system to evaluate product shape and features (Figures 18 and 19).

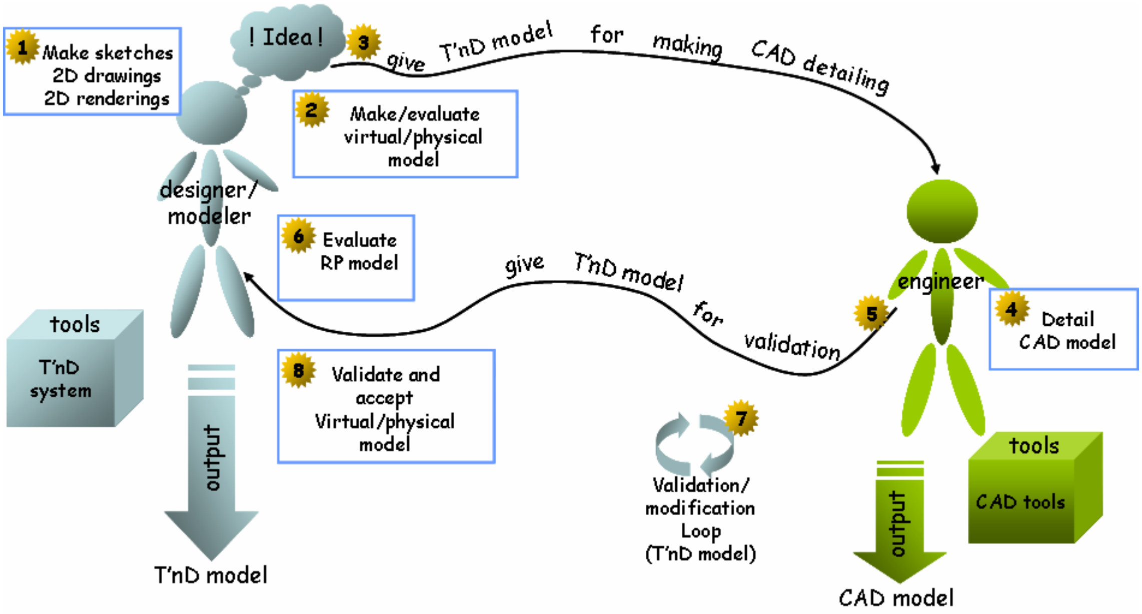


Figure 18. Schematic representation of the long-term T'nD process.

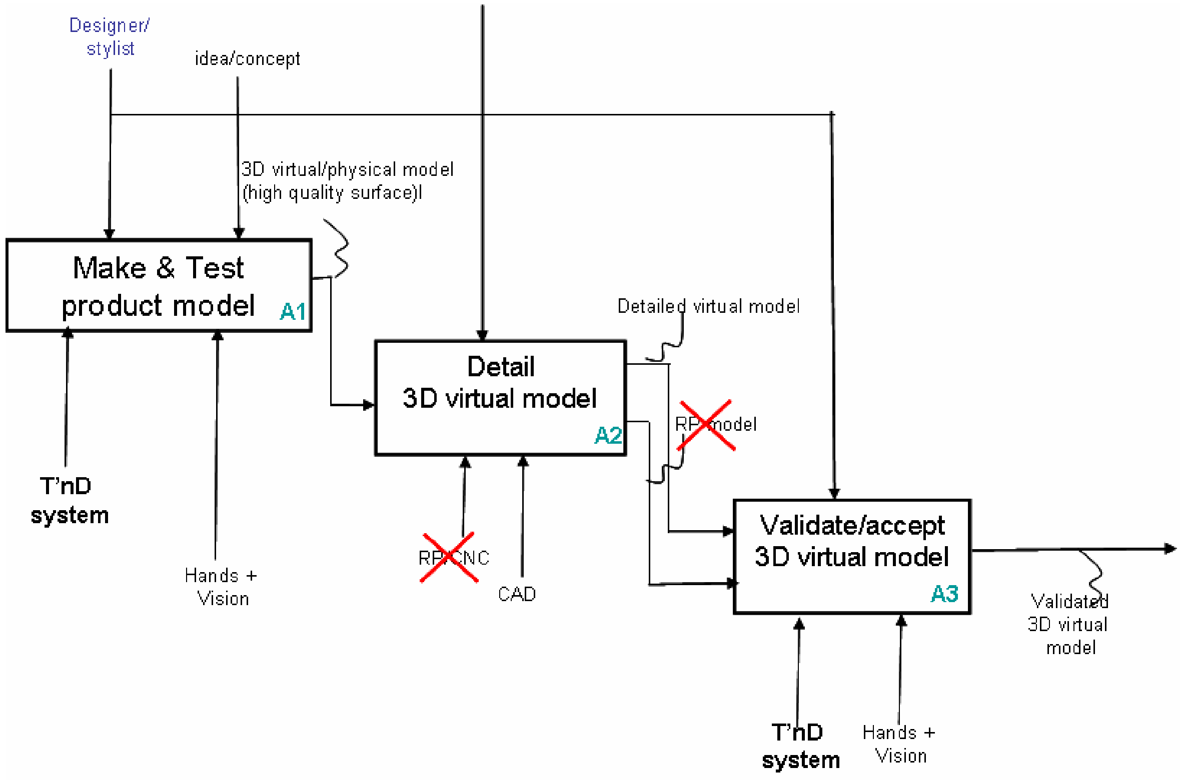


Figure 19. IDEF0 diagram describing the long-term T'nD process.

5. Scenarios

5.1. Introduction

Scenarios are defined on the basis of system requirements and short-term and long-term technological goals. The aim of the scenarios is presenting the main features of the T'nD system and how it will operate. Two types of scenarios are proposed. The first one is a *short-term scenario* that demonstrates the use and performances of the T'nD system in shape creation and evaluation. The scenario shows:

1) improvements in shape modeling technology alone;
2) improvements in haptic technology alone;
3) improvements in the process and in the ways of doing things, and exploiting skills due to integration of shape modeling and haptic technologies extended with novel interaction metaphors and devices.

The second one is a *long-term scenario* that describes how a shape modeling system based on haptic interaction might be according to IT providers' long-term vision about technological evolution in the two addressed fields (as described in Chapter 2). The short-term scenario is going to be used to demonstrate, validate and assess with users the concepts behind the T'nD system. The long-term scenario is going to be used to check if the evolution trend of technology is such that users' expectations will be fully or partially satisfied. This is useful to understand if IT functionalities and users' requirements are going to converge at a certain point in the near future.

5.2. T'nD short-term Scenario

5.2.1. Goals of the T'nD short-term Scenario

T'nD short-term Scenario shows in an easy way, and understandable by a wide audience, how the innovations produced by the T'nD project will affect the process and the way of doing things, and will exploit existing skills and procedures. Its aim is on one side to communicate and diffuse T'nD to the targeted community, and on the other side to collect feedback on T'nD concept, environment and systems by the community. The Scenario is implemented as a visual presentation of the T'nD environment using a visionary animation movie. The The scenario is targeted to the following four categories of users: designers and modelers, technology providers, researchers, managers.

5.2.2. Modeling actions

On the basis of observations of modelers at work done in *WP2 – Users' skill capture and analysis*, and further discussions with end-users, the following modeling actions have been pointed out as desirable to be included in T'nD:

- *Scraping actions*
  - o The modeler removes material from a block using some tools like a rasp (Figure 20).
- *Quality check actions*
  - o The modeler checks the surface quality using hands motions (Figure 21).
- *Finishing actions*
  - o The modeler finishes the object using tools like sand paper (Figure 22). This is a double action, since it allows the modification of the shape on the basis of the quality of shape perceived during the operation in real time.

Some other actions are also desirable, but will less priority, such as adding material.

Figure 20. – Modeler performing scraping actions using a rasp (courtesy of Pininfarina).

Figure 21. – Modeler performing quality checking actions using hands (courtesy of Alessi).

Figure 22. – Modeler performing finishing actions using sand paper (courtesy of Alessi).

5.2.3. Modeling tools&operators

In order to implement the various types of actions, the following shape modeling tools and operators have been defined. *Modeling tools* are physical and corresponding virtual devices the user uses to create, modify and evaluate the object surface. Tools shape varies, according to the type of action they are used for. For example, there are scraping tools, or finishing tools. *Modeling operators* are paradigms and metaphors that the system proposes for accomplishing a given action in an intuitive and easy way.
The three following operators propose interaction modalities that are evocative of how real modelers actually work in real life.

Scraping tool&operator

The scraping operator is evocative of the rasp and templates and steel plates used by modelers to sculpting the surface. The tool used relates to the rasp that is operated by the modelers by handling it usually with two hands. The tool can be used for engraving a solid, and also as round operator, for making edges less sharp. The scraping tool might have simple shape (straight line) or might be complex. The shape will be discussed and decided according to the evaluation of technological feasibility.

Finishing tool&operator

The finishing operator is evocative of the sandpaper used by modelers to finish and smooth the surface. The tool used relates to the sand-paper operated by the modeler with his full hand for removing exceeding material with high precision.

Surface quality check tool&operator

The surface quality check operator is evocative of the modelers’ hands moved over the surface to check its quality and to assess the shape styling features. The tool used should convey users’ information about the object surface quality (continuity, smoothness, etc.) with high precision in order to exploit their existing skills.

The discussion with users has also pointed out the interest in being able to perform a sort of *shape deformable action,* where the object shape is modified by inflating the surface defining it. This would be a completely new environment having no relations with the actual practice and reality.

Deformation tool&operator

The deformation operator is not evocative of any modellers’ activity but is something very new and innovative that would enhance modeling performances and way of interaction with the model. The tools would be used for stretching the surface, by enlarging and distending the solid as it would be a piece of plasticine.

In addition, more conventional operators like copy&paste, duplicate, mirror, change scale, etc. will be available.

5.2.4. Haptic tools

In order to support the various types of actions the users should be able to perform for freely creating, modifying and evaluating an object shape through scraping, finishing and quality check actions, the haptic tools should provide an appropriate number of degrees of freedom. At the moment, the FCS-HapticMaster (HM) device offers three degrees of freedom. In order to support the identified actions, the number of d.o.f. should be increased. *WP5 – System conception* plans the study and design of a tool to be mounted onto the current version of the HapticMaster in order to provide a device offering 6 d.o.f.
Before studying the haptic system, some hypotheses have been done on how it could be. The different solutions presented in Figure 23 are distinguished on the basis of:

- number of HapticMaster devices
- system d.o.f.

- shape of end tool

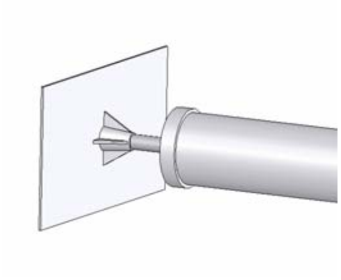
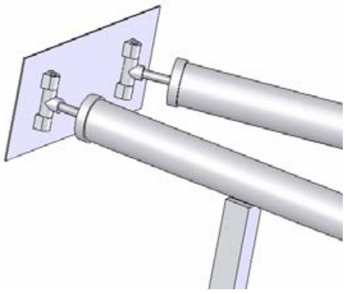
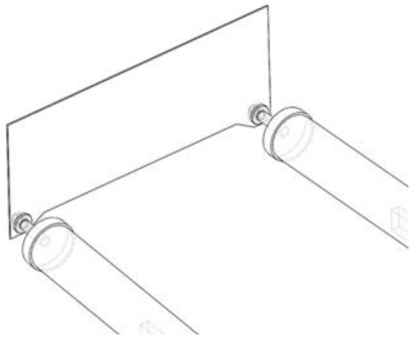
Images of tools	Description
	Solution using 1 HapticMaster device, where the tool is connected to the HM though a rigid connection. The system has 3 d.o.f.
	Solution using 2 HapticMaster devices connected to a tool by means of cylindrical joints. The system has 4 d.o.f.
	Solution using 2 HapticMaster devices connected to a tool by means of spherical joints. The system has 5 d.o.f.
	Solution using 2 HapticMaster devices using a new handling tool. The system has 6 d.o.f.
T'nD haptic tool (under development)	Solution using 1 HapticMaster device (3 d.o.f.) connected to novel tool(s) providing 3 more d.o.f.

Figure 23. – Haptic system proposed solutions.

5.2.5. System integration

The final integrated system consists of the innovative haptic tool integrated with the modeling operators. The following storyboard describes how the integrated system might work. In the following we describe a Scenario that presents the T’nD system and its functionality.

Description of the Scenario

Environment

The environment consists of an innovative haptic system and an innovative shape modeling system, and of a framework that integrates them.

User

The user of the T’nD system is expected to be a designer or a modeler who is not used to work with CAS/CAD tools.

Tasks

The user of the T’nD system manipulates the haptic system in order to remove and scrape material from an initial block, to smooth and finish the object shape, and to check the object surface quality, and to deform the surface shape.

Scenario storyboard

The storyboard is a series of visual images that simply and briefly illustrate the T’nD Scenario environment, tools and tasks. The storyboard shows all information that is important and we think will help the audience understand how T’nD system works. The storyboard consists of the following visual images:

1. *T’nD environment*
   The environment consists of a screen where the digital model is visualized, and a haptic system that is manipulated by a user (designer or modeler).
2. *Haptic tools*
   The haptic tools available are:
   - ❖ two-handle tool with variable profile and flexibility (acting as a rasp)
   - ❖ deformable plate-tool (acting as sand-paper or user’s bare hand)
   - ❖ deforming wand-tool
3. *Modeling tasks*
   The T’nD system presents an initial shape made of a malleable material the user can choose (clay, wood, etc.). The user starts modifying the shape by performing the following operations:
   - ❖ use the two-handle tool for removing thick pieces of material
   - ❖ use the deformable plate-tool (leaning the hand on it) for checking the surface quality
   - ❖ use the deformable plate-tool (leaning the hand on it) for smoothing the surface
   - ❖ use the deforming wand-tool for inflating and deforming the surface
4. *Virtual object manipulation*
   The virtual object can be rotated or translated using two modalities:
   - ❖ 3D device
   - ❖ voice command
5. *System feedback*
   The T’nD system provides several types of feedback to the user:
   - ❖ visual representation of the tool (tool avatar) in the virtual environment
   - ❖ haptic feedback of the interaction with the object surface
   - ❖ visual representation of the contact forces vector
   - ❖ visual deformation of the object shape in response to users’ tasks
   - ❖ reflection lines drawn over the surface shape
6. *System output*
   The T’nD system provides as output a class-A surface of the created object that can be immediately used with a CAD tool.

Some animations showing the T'nD system at work is available in order to demonstrate the T'nD environment and how the system will work. Figures 24 and 25 show some images of the animated scenario.

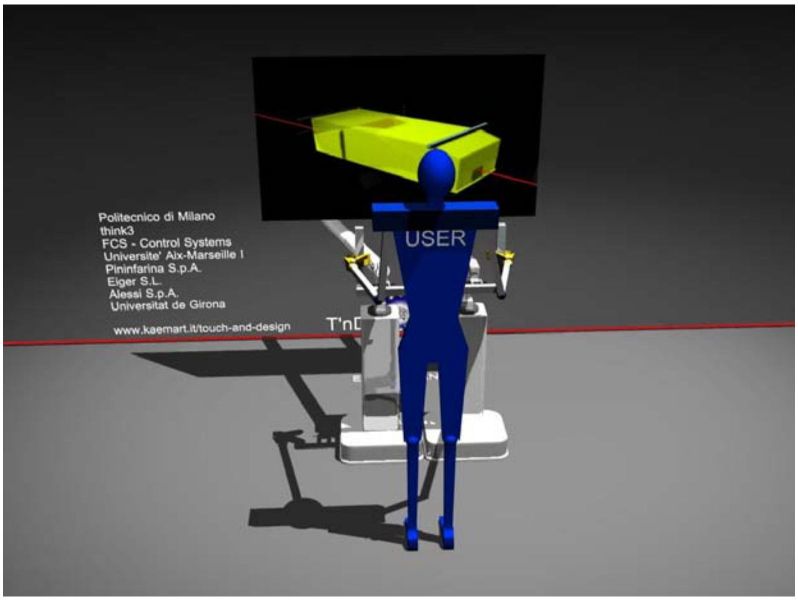


Figure 24. – Image from the Scenario: User is scraping an object surface.

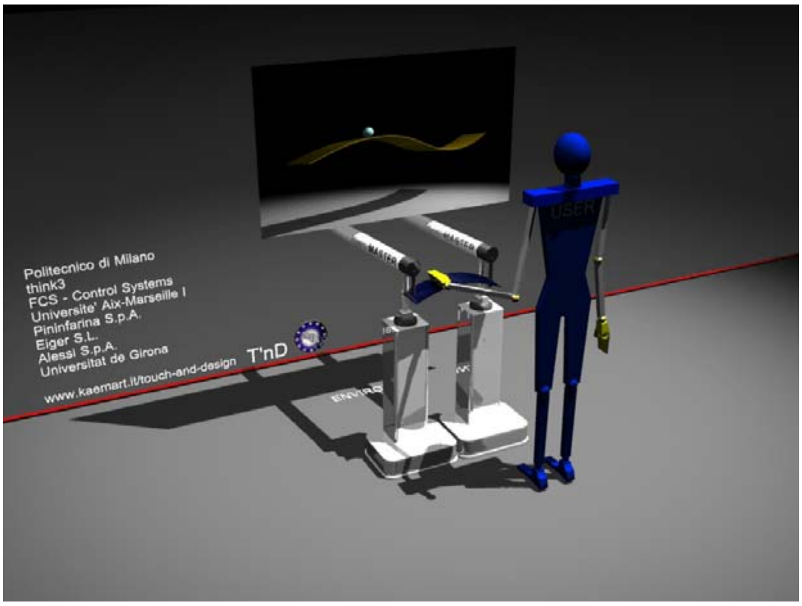


Figure 25. – Image from the Scenario: User is checking an object surface quality.

5.2.6. Evaluation of T’nD Scenario

The storyboard and the animation of the T’nD short-term Scenario have been shown to some users from T’nD partners in order to perform a first evaluation of the T’nD concepts obtaining a very good response. In any case, the Scenario will be described and the animation shown to a much larger audience, such as heads of product design departments, designers and modelers, CAD engineers outside the project. All those people will be asked to fill in the questionnaire reported in Annex 1. The results of the Scenario evaluation will be reported in a future document.

5.2.7. Feasibility in T’nD

After discussion among partners, the following shape modeling tools and operators have been pointed out as the most desirable for the end users and are considered feasible in the context of the T’nD project by the IT providers:

- Scraping tool&operator
- Finishing tool&operator
- Surface quality check tool&operator

The scraping, finishing and surface quality check tools will be implemented using one HapticMaster equipped with one or several appropriate haptic tools. The tool(s) will be studied, designed and developed in *WP5 – System Conception* of the project.
(Note: were it not possible because of technological limitations, a recovery solution might be to implement the tools using two HapticMaster devices.)
The *deformation tool&operator* is a completely new approach that implies a new interaction metaphor. Therefore, new devices and interaction paradigms should be further studied and investigated.

5.3. Long-term scenario

5.3.1. Introduction

The long-term scenario describes a future, let’s say 10 years, vision of how an innovative system would work. The future scenario comes from end users’ requirements (chapter 3), and from long-term vision of technology providers about the technology evolution (chapter 2), and from brainstorming sessions of the project partners.
The scenario implements a completely innovative way of interacting with the application, where technology is as much as possible invisible and transparent to users. The interaction with system functionalities is not mediated by the technology, or it is not intrusive and the users are able to freely and intuitively work without caring about devices manipulations. One example of such technology is offered today by tactile display [5, 6, 7].
In the long-term that is beyond the demonstration of the T’nD concept and feasibility, the development of a handy workable haptic tool for designers should do the following:

- Give the designer the capability to perform on a virtual material all the *operations* which are usually performed by modelers in the physical environment, while at the same time not necessarily mimicking the *modus operandi* of the existing modelers’ tools.
- Provide virtual tools which give the opportunity to and demand to the designer the exertion of some degree haptic strength and of a high degree of manual, namely digital skill.
- Dispense the designer with time-consuming operations of taking away unnecessary material, which the existing tools require from the modelers.
- Provide the designer with a variety of virtual material for modeling, together with a possibility to parametrize the simulated physical properties of such virtual material.
- Provide the designer with a variety of tools properties parameter together with a large degree of flexibility in the tools characteristics in terms of speed of operation, shape characteristics, efficiency and so on.
- Support a large variety of rapid prototyping techniques for the actualization and rendering of the virtual model.
- Support co-design activities of several users.
- Be compatible with CAGD, as both in- and output.

5.3.2. Characteristics of long-term Scenario

Facilitating the designer’s expression

Attention should be carefully given to the ergonomics of the following:

- tools instructions to the user;
- tool-user communication: menu and parameter for manual tools should be operated through vocal command;
- haptic feedback provided by more friendly, natural and easy to use tools that support a better exploitation of designers’ skills they have when creating shapes by hands. The envisaged haptic tool might be an evolution of the tactile devices and haptic windows (see § 2.3);
- action feedback: in order to simulate the possibility of looking closer, or to check by hand sweeping a surface finish, the T’nD user should be given the possibility to zoom, so to speak on the model in the process of being modeled;
- action evaluation: the designer should be assisted with CAD facilities with respect of coloring and texturing the surfaces of his model.

Facilitating the designer’s communication

T’nD models should be easily converted into other types of representation, such as technical drawing, virtual imagery, or solid prototyping, in order to help the designer in discussing the model in progress with other members of the design studio, as well as with marketing people, customers and clients and so on.

Shortening the design workflow

T’nD should be connected with existing CAD system in order to communicate easily with other representations of the object being designed, and to make easy and fast interaction with other participant in the design process.

Some animations showing the T’nD long-term Scenario has been implemented in order to demonstrate how the future system might be. Figure 26 shows a snapshot of the long-term scenario.

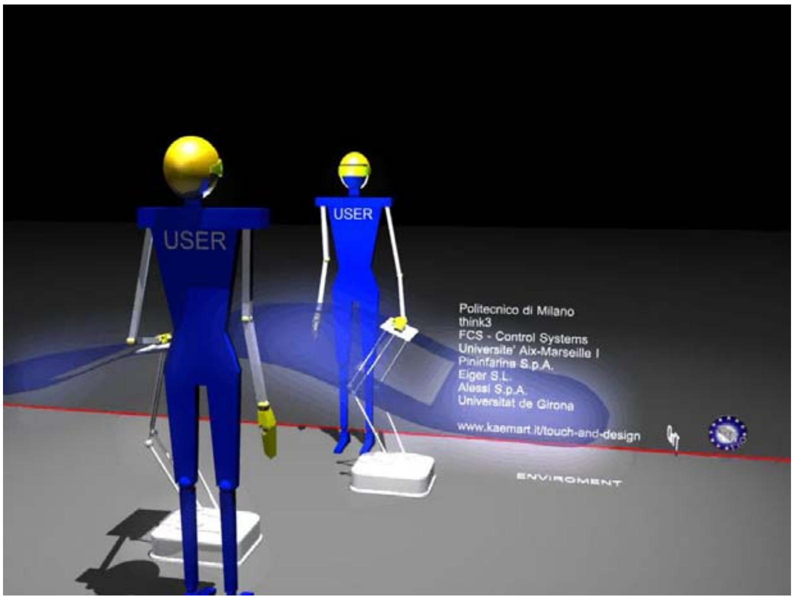


Figure 26. – Image from the long-term Scenario.

6. Test Cases

6.1. Introduction

The test cases are used to test the T’nD system concept, functionality and usability with users.
It is planned to run two rounds of test cases. The first round aims at collecting comments, suggestions, and questions, concerning the prototype developed in the early development phase of the project available at the end of the first year (a very preliminary prototype is developed in *WP3 – Theoretical foundations*). The test results are used to get users’ feedback about the conceptual aspects of the conceived system, to improve, and modify the system design if it does not satisfy users’ requirements, to get further input for the system specification phase.
The second round (that will be performed in *WP7 - Evaluation*) aims at validating (technical aspects) and evaluating (performances, benefits, etc.) the final version of the T’nD system, at measuring users’ satisfaction in respect to initial expectations and requirements.
Therefore, the questions to be addressed are the following:

1. If and how T’nD might improve product design process performances
2. How users feel T’nD is working
3. How do they appreciate its functioning
4. How does T’nD compare with CAS/CAD modeling

Questions 1, 2, 3 and 4 will be explored through evaluation sessions and interviews with professionals, namely:

- End-users partners in the T’nD project
- Professionals of other companies
- Customers of end-users

Question 4 will be also explored through a planned and standardized shape modeling task, with the cooperation of students of the Faculty of Industrial Design from Politecnico di Milano, and from Universitat de Girona.

The following sections describe the methodological approach we intend to use for running the test cases, the test case planned to evaluate the first T’nD prototype, and the test cases planned to evaluate and validate the final T’nD system with professionals and with design students.

6.2. Methodological approach: Roadmap

The following table shows a sequence of activities, and their description, that are carried out for conducting all test cases.

ACTIVITY	DESCRIPTION
1. Description of Test Case	
1.1 Goal	Description of the goal of the Test Case
1.2 Setup	Description of the set up of the Test Case: hardware, software, configurations, etc.
1.3 Description	Description of how the Test Case is going to be run
2. Users	Description of the users that will participate to the Test Case
3. Questionnaire 1	Questionnaire that is used to identify the tester’s background and profile
4. Run test case	
4.1 Training and adaptation	Description of the training phase necessary for testers to get used to the system
4.2 Explanation of goal and tasks to testers	Description of the goal and the tasks the tester is required to perform

4.3 Performance of task	Performance is video recorded.
5. Questionnaire 2	Questionnaire that is used to evaluate testers' experience
6. Analysis of results	The contents of the interviews are analyzed, and some comments and results are provided.

6.3. Test Case for T'nD prototype validation

An initial Test Case is set up and run in order to collect comments, suggestions, and questions, concerning the prototype developed in the early development phase of the project (at the end of *WP3 – Theoretical foundations*). Since the new haptic tool will be available later on in the project, the partners have studied some solutions for performing some initial experiments and validations using the current available HapticMaster device. The prototype has been built using two HapticMaster devices connected by a proper tool that allows for 5 d.o.f. (see § 5.2.3). This system is a very preliminary solution, but anyway allows us to gather opinions and suggestions from users about the T'nD concept. The following table describes the Test Case that has been run at Politecnico di Milano, where the system has been installed, at the end of year 1 of the project.

6.3.1. Roadmap

ACTIVITY	DESCRIPTION
1. Description of Test Case	
1.1 Goal	The test case aims at assessing system concepts by collecting comments, suggestions, and questions, concerning the prototype developed in the early development phase of the project.
1.2 Setup	The test case has been set up at Politecnico di Milano and consists of two HapticMaster devices connected by a two-handle tool.
1.3 Description	The system can be used for removing material from an initial shape that is represented on the screen, and can be touched.
2. Users	The users testing the system are: - designers (Alessi, Eiger, Pininfarina) - modelers (Alessi, Eiger, Pininfarina) - designers and modelers (company external to T'nD) - students of the Industrial Design Faculty of PoliMI - faculty members of Dept. of Mechanical Engineering and of Industrial Design of PoliMI.
3. Questionnaire 1	Testers are asked to fill in an initial questionnaire in order to identify their background and profile (see Annex 2 - Questionnaire 1).
4. Run test case	
4.1 Training and adaptation	Users are given 5 minutes to get acquainted to the system, in order to understand the tools and to control the interaction. The users can scrape the initial material freely.
4.2 Explanation of goal and tasks to users	The users are asked to perform the following task: touch and scrape an initial piece of material in order to feel the surface and remove material.
4.3 Performance of task	Tasks performed by users are video recorded. Some questions/interviews might be done by developers during task execution.
5. Questionnaire 2	Testers are asked to fill in a second questionnaire in

	order to evaluate their experience (see Annex 2 – Questionnaire 2).
6. Analysis of results	Results of testing and comments from users are used to assess the system concepts, and to improve T’nD system specification, functionality. A table will be provided considering test results/users’ comments → actions to take in T’nD for improvement

6.4. Test Cases for T’nD system validation with professionals

Test Cases are defined on the basis of results of analysis and findings of *WP2 – Users’ skill capture and analysis*, and of the short term Scenario. They are defined by end users, according to their interests, and by IT providers, according to their perception of what is feasible for what concerns technology improvement and feasibility in the timeframe of the project.
The Test Cases aim at validating the concept, approach, new process benefits, main system features and functionality, cognitive and functional performances and usability of the T’nD system.

The evaluation methodology consists of setting up the system, and performing Test Cases using various types of users and sessions, and evaluating them applying the defined metrics. Users are given a task and are allowed to think aloud. The interaction between experimenter and the user after task assignment is minimal in order to create a situation that is a very close approximation of expected individual usage of the system. Users’ interaction sessions are video recorded.

Users
The test cases will be run involving several types of users:

- Professionals within T’nD: modelers, designers, users that are both modelers and designers
- Professionals external to T’nD: modelers, designers, users that are both modelers and designers
- Customers of end users.

Professional users from both automotive industry and home products industry will be proposed to perform a modeling task they are familiar using the T’nD system.

Questionnaire 1
Testers are asked to fill in an initial questionnaire in order to identify the role, skill, knowledge of the user (Annex 3 – Questionnaire 1).

Tasks for users

- Testers are given a sketch of products decided together with end-users, so as all system modeling features (types of motions described in deliverable D5) can be evaluated.
- Testers are asked to create the shape with T'nD.
- Testers are then asked to modify the shape (to improve it and imagine some alternatives)

Questionnaire 2
After the performance the testers will be invited to a non directive interview where the following issues will be considered with respect to the T’nD prototype. The questions aim at providing values for the parameters included in the metrics presented in *§* 6.6.

1. Perceived usefulness
   (process benefits, performances, satisfaction with the overall performances)
2. Perceived usability
3. Enjoyment with tool
4. Evaluation of physical tool
5. Evaluation of visual aspects

6.5. Evaluating T’nD with design students: usability assessment of T’nD system

While the test cases for professionals might be different according to the company, the test has to be exactly the same for all the design students, in order to have a perfectly reliable and sound comparison. Therefore, the same sketch will be used for this evaluation. The testers will be students from the design schools from Politecnico di Milano and from Universitat de Girona. Test given to all the students will be either a vaccuum cleaner or a C-pilar exclusively. They will be asked to make the solid model (either actual or virtual) of the object. They will model either with plastic material, with CAS/CAD, or with T’nD.

6.5.1. Test settings and procedure

Users

30 design students, half of them from Politecnico di Milano, the other half from the Universitad de Girona, of equivalent on the average, according to age, level in the curses, and grade, will be selected.

In each location, the 15 students from the local University will be distributed randomly in three groups of five.

Each group will be assigned a different task:

- Group 1: modeling with malleable materials.
- Group 2: modeling with CAS/CAD.
- Group 3: modeling with T’nD.

Jury

A panel of judges will be set up in order to evaluate the outputs from the tests, including:

- Two academic members of each University Design department.
- Two members from the T’nD research project.
- Two members of the end-users’ companies, one from the car industry, the other from products industry.

Tasks for users

1. Every student will be told about the goal of the test, and given assurances that the test holds no relation with his/her academic evaluation.
2. Every student will be trained in T’nD handling.
3. Then the student will show the sketch of the object to be modeled (the same object for all students).
4. Then, according to the group he/she had been randomly assigned, the student will be asked to model the object, either with T’nD, CAS/CAD, or in malleable material.
5. When the time allowed for the modelling is over, a 3-orthogonal-view photograph or CAD drawing is recorded, while the student gets some rest.
6. After this pause, the student is asked to look back at his model, and try to imagine, and perform some improvement of the model, using the same modeling technique.
7. When the time allowed for improving the model is over, views of the output are again registered. The two modeling sessions are video recorded.
8. The student is then asked to fill in a final questionnaire, and then after, is thanked for his/her participation.

Rating the outputs

The jury will be presented with:

1. The views of the 30 models made in phase 1, and asked to first rank order them according to accuracy of modeling, and quality of finish.
2. The views of the 30 improved models, and asked to rank order them according to the ingenuity and esthetic value of the improvements made, if any.
3. For the five highest, and the five lowest ranking models, to fill in a short questionnaire.

6.6. Evaluation Metrics

An evaluation metrics has been defined for assessing the T'nD system. It consists of a set of indicators that will be evaluated by direct measuring or through answers to questions included in the questionnaires.

	Parameter	Description	Type of measurement	How/when to measure it
User's performance				
	Total time	Total time required to produce the model of a product	Quantitative (minutes)	Measured from start to end of test case activity
	Time for implementing modification	Time required to implement a modification onto the model	Quantitative (minutes)	Measured during performance of test case activity
	Test/modification Iterations	Number of times the model is modified before reaching the final model	Quantitative (number)	Measured during performance of test case
	Number of solutions tested	Number of solutions and variants of product model that can be created	Quantitative (number)	Measured during performance of test case
Usefulness				
	Usefulness for shape creation	Usefulness of T’nD for creating rough or precise shapes	Verbal statement	Asked in questionnaire 2
	Usefulness for shape modification	Usefulness of T’nD for modifying shapes roughly or precisely	Verbal statement	Asked in questionnaire 2
	Usefulness for shape evaluation	Usefulness of T’nD for evaluating the quality of the shapes	Verbal statement	Asked in questionnaire 2
	Improvement of quality of product model (shape complexity)	Perception of improvement of product model quality	Verbal statement	Asked in questionnaire 2
	Usefulness and benefits for designers and/or modelers	Usefulness and benefits derived from using T’nD for designers and/or modelers	Verbal statement	Asked in questionnaire 2
Usability				
	Learnability	Easiness to learn and start using the T'nD system	Verbal statement	Asked in questionnaire 2
	Intuitiveness of hand motions	Hand motions allowed by the system are intuitive?	Verbal statement	Asked in questionnaire 2
	Efficiency of hand motions	Motions supported by the system allow obtaining the expected shapes?	Verbal statement	Asked in questionnaire 2
	Exploitation of users’ skill	The system allows users exploiting their skills in modeling	Verbal statement	Asked in questionnaire 2
	Usability of the haptic device	Evaluation of usability aspects of the haptic device: intuitiveness, explicit control, etc.	Verbal statement	Asked in questionnaire 2
	d.o.f. of haptic device (freedom	Is the number of degree of freedom offered by the haptic	Verbal statement	Asked in

	in movement of tool)	system enough?		questionnaire 2
	Force feedback	Force feedback exerted by the system is too strong, too low, etc.	Verbal statement	Asked in questionnaire 2
	Dimension of haptic system workspace	Haptic system workspace is enough	Verbal statement	Asked in questionnaire 2
	Quality of graphic/visual interaction	The quality of the graphic/visual rendering is good enough, information visualized is clear, etc.	Verbal statement	Asked in questionnaire 2
Enjoyment				
	Enjoyment in using T'nD	The enjoyment felt while using the T'nD system	Verbal statement	Asked in questionnaire 2
	Comparison with enjoyment while using CAS/CAD tools	Comparison with the enjoyment felt while using CAS/CAD systems	Verbal statement	Asked in questionnaire 2
	Comparison with enjoyment while drawing or modeling with hands	Comparison with the enjoyment felt while drawing or modeling whith hands	Verbal statement	Asked in questionnaire 2
System performance and functions				
	Quality and precision of obtained surfaces	The surface obtained are precise enough, well describe the object.	Verbal statement	Asked in questionnaire 2
	Evaluation of modeling operators	Operators allow obtaining any desired shape. Do they work well? The modification operators are good, and work well?	Verbal statement	Asked in questionnaire 2
	Evaluation of model transformation operators	The operators for applying rigid transformations (rotation and pan) are good, works well.	Verbal statement	Asked in questionnaire 2
	Evaluation of surface quality check operators (tactile and reflection lines)	The operators for checking the surface quality work well? Give enough information about the surface quality?	Verbal statement	Asked in questionnaire 2
	Comparison of shape modeling operators with the ones offered by other CAS/CAD tools	The modeling operators provide the same or better performance of similar operators in other CAS/CAD tools?	Verbal statement	Asked in questionnaire 2

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Annex 1 – Questionnaire for Scenario evaluation

Questionnaire 1

To complete before seeing the Scenario.

1. Specify your function/role:

Designer	☐
Modeler	☐
Designer & Modeler	☐
CAD engineer	☐
Student	☐
Other	________________

2. Use of computer

2.1 Do you use computer to:

	little				lot
Develop new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.2 Type of input devices you use:

	yes	no
Mouse	☐	☐
Keyboard	☐	☐
Tablet PC	☐	☐
Digitizer	☐	☐
Haptic tool	☐	☐
Other	________________	

2.3 Type of graphic/modeling tool you mostly use:

	yes	no
2D paint	☐	☐
2D sketches	☐	☐
2D CAD	☐	☐
3D CAS	☐	☐
3D CAD	☐	☐
Other	________________	

2.4 Evaluate the effectiveness of the tools you mostly use with regard to:

	☹				☺
Developing new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.5 Evaluate the following aspects of the tool you mostly use:

	☹				☺	N.A.
Ease of initial learning	☐	☐	☐	☐	☐	☐
Ease of use after learning	☐	☐	☐	☐	☐	☐
Interactivity	☐	☐	☐	☐	☐	☐
Intuitiveness	☐	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐	☐
Precision	☐	☐	☐	☐	☐	☐
Time saving	☐	☐	☐	☐	☐	☐
Quality of shape	☐	☐	☐	☐	☐	☐
Reuse of results	☐	☐	☐	☐	☐	☐

Support for task performance (results achieved as expected/desired)?	☐ ☐ ☐ ☐ ☐ ☐

3. Use of malleable materials

3.1 Type of material you use:

	yes	no	
Clay	☐	☐	
Wood	☐	☐	
Foam material		☐	☐
Other	________________		

3.2 Do you use physical prototyping to:

	little … lot
Develop new concepts	☐ ☐ ☐ ☐ ☐
Produce physical models from others' ideas	☐ ☐ ☐ ☐ ☐
Communicate ideas to others	☐ ☐ ☐ ☐ ☐
Detail concepts	☐ ☐ ☐ ☐ ☐

3.3 Evaluate the effectiveness of physical prototyping for:

	☹ … ☺
Develop new concepts	☐ ☐ ☐ ☐ ☐
Produce physical models from others' ideas	☐ ☐ ☐ ☐ ☐
Communicate ideas to others	☐ ☐ ☐ ☐ ☐
Detail concepts	☐ ☐ ☐ ☐ ☐

Questionnaire 2

To complete after seeing the Scenario.

Perceived usefulness

Q1. Concerning the following aspects, do you think the proposed T'nD system is bad or good?

	☹				☺
For shape creation	☐	☐	☐	☐	☐
For shape finishing	☐	☐	☐	☐	☐
For surface quality control	☐	☐	☐	☐	☐
For product design	☐	☐	☐	☐	☐
For designers	☐	☐	☐	☐	☐
For modelers	☐	☐	☐	☐	☐
For CAD engineers	☐	☐	☐	☐	☐

Q2. Do you think T'nD system could integrate/replace:

	integrate	replace	NA
2D drawing tools	☐	☐	☐
3D CAS tools	☐	☐	☐
3D CAD surface	☐	☐	☐
3D CAD solid	☐	☐	☐
Multimodel (physics-based)	☐	☐	☐
Hand-made prototypes	☐	☐	☐
RP prototypes	☐	☐	☐
Other	______________________		

Perceived usability

Q3. Do you agree with the following points of view?

	☹				☺
It is easy/intuitive creating shapes	☐	☐	☐	☐	☐
The hand motions/gestures are intuitive	☐	☐	☐	☐	☐
The gestures are similar to physical modeling gestures	☐	☐	☐	☐	☐
The haptic tool seems easy to use with two hands	☐	☐	☐	☐	☐
The environment set-up (haptic+vision) seems effective	☐	☐	☐	☐	☐
It is easy to undo or modify what you have done	☐	☐	☐	☐	☐

Enjoyment

Q4. How do you feel with the T'nD system?

	☹				☺
Did you enjoy to use the T'nD system	☐	☐	☐	☐	☐
Did you enjoy it more than using CAS/CAD tools?	☐	☐	☐	☐	☐
Did you enjoy it more than drawing/modeling with hands?	☐	☐	☐	☐	☐

	yes	no
Q5. Do you think that users' skill may be well exploited by the system?	☐	☐

Q6. Do you think that other operators or functions would make the system more useful, powerful, usable?

____

____

Q7. Any other suggestions for improving the system?

____

____

Annex 2 – Questionnaire for Prototype evaluation

Questionnaire 1

To complete before using the prototype.

1. Specify your function/role:

Designer	☐
Modeler	☐
Designer & Modeler	☐
CAD engineer	☐
Student	☐
Other	________________

2. Use of computer

2.1 Do you use computer to:

	little				lot
Develop new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.2 Type of input devices you use:

	yes	no
Mouse	☐	☐
Keyboard	☐	☐
Tablet PC	☐	☐
Digitizer	☐	☐
Haptic tool	☐	☐
Other	________________	

2.3 Type of graphic/modeling tool you mostly use:

	yes	no
2D paint	☐	☐
2D sketches	☐	☐
2D CAD	☐	☐
3D CAS	☐	☐
3D CAD	☐	☐
Other	________________	

2.4 Evaluate the effectiveness of the tools you mostly use with regard to:

	☹				☺
Developing new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.5 Evaluate the following aspects of the tool you mostly use:

	☹				☺	N.A.
Ease of initial learning	☐	☐	☐	☐	☐	☐
Ease of use after learning	☐	☐	☐	☐	☐	☐
Interactivity	☐	☐	☐	☐	☐	☐
Intuitiveness	☐	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐	☐
Precision	☐	☐	☐	☐	☐	☐
Time saving	☐	☐	☐	☐	☐	☐
Quality of shape	☐	☐	☐	☐	☐	☐
Reuse of results	☐	☐	☐	☐	☐	☐

Support for task performance ☐ ☐ ☐ ☐ ☐ ☐
(results achieved as expected/desired)?

3. Use of malleable materials

3.1 Type of material you use:

	yes	no	
Clay	☐	☐	
Wood	☐	☐	
Foam material		☐	☐
Other	________________		

3.2 Do you use physical prototyping to:

	little				lot
Develop new concepts	☐	☐	☐	☐	☐
Produce physical models from others' ideas	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

3.3 Evaluate the effectiveness of physical prototyping for:

	☹				☺
Develop new concepts	☐	☐	☐	☐	☐
Produce physical models from others' ideas	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

Questionnaire 2

To complete after using the prototype.

Perceived usefulness

Q1. Concerning the following aspects, do you think the proposed T'nD system is bad or good?

	☹				☺
For rough shape creation	☐	☐	☐	☐	☐
For precise shape creation	☐	☐	☐	☐	☐
For product design	☐	☐	☐	☐	☐
For designers	☐	☐	☐	☐	☐
For modelers	☐	☐	☐	☐	☐
For CAD engineers	☐	☐	☐	☐	☐

Q2. Do you think T'nD system could integrate/replace:

	integrate	replace	NA
2D drawing tools	☐	☐	☐
3D CAS tools	☐	☐	☐
3D CAD surface	☐	☐	☐
3D CAD solid	☐	☐	☐
Multimodel (physics-based)	☐	☐	☐
Hand-made prototypes	☐	☐	☐
RP prototypes	☐	☐	☐
Other	____________________		

Perceived usability

Q3. Do you agree with the following?

	☹				☺
It is easy/intuitive creating shapes	☐	☐	☐	☐	☐
The hand motions/gestures are intuitive	☐	☐	☐	☐	☐
The motions are similar to physical modeling motions	☐	☐	☐	☐	☐
It is easy to use the device with two hands	☐	☐	☐	☐	☐
The motions allowed enable to obtain the expected shape	☐	☐	☐	☐	☐
It is easy to understand the relation between the manual movements and the result	☐	☐	☐	☐	☐
The system allows the exploitation of your skill	☐	☐	☐	☐	☐

Interactive physical tool

Q4. Do you agree with the following?

	☹				☺
Ease of initial learning	☐	☐	☐	☐	☐
Ease of use after learning	☐	☐	☐	☐	☐
The device is a good metaphor of the rasp	☐	☐	☐	☐	☐
You feel comfortable with the device	☐	☐	☐	☐	☐
The force feedback is too strong	☐	☐	☐	☐	☐
The force feedback is too low	☐	☐	☐	☐	☐
The workspace is good enough	☐	☐	☐	☐	☐
The manual feelings are coherent with the visual effects	☐	☐	☐	☐	☐
The manual feelings should be improved	☐	☐	☐	☐	☐

Q5. Do you think that other operators of functions would make the system more useful, powerful, usable? Which ones? (drawings are possible)

Q6. Any other suggestions for improving the system?

Annex 3 – Questionnaire for T'nD system evaluation

Questionnaire 1

To complete before using the T'nD system

1. Specify your function/role:

Designer	☐
Modeler	☐
Designer & Modeler	☐
CAD engineer	☐
Student	☐
Other	________

2. Use of computer

2.1 Do you use computer to:

	little				lot
Develop new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.2 Type of input devices you use:

	yes	no
Mouse	☐	☐
Keyboard	☐	☐
Tablet PC	☐	☐
Digitizer	☐	☐
Haptic tool	☐	☐
Other	________	

2.3 Type of graphic/modeling tool you mostly use:

	yes	no
2D paint	☐	☐
2D sketches	☐	☐
2D CAD	☐	☐
3D CAS	☐	☐
3D CAD	☐	☐
Other	________	

2.4 Evaluate the effectiveness of the tools you mostly use with regard to:

	☹				☺
Developing new concepts	☐	☐	☐	☐	☐
Communicate ideas to others	☐	☐	☐	☐	☐
Detail concepts	☐	☐	☐	☐	☐

2.5 Evaluate the following aspects of the tool you mostly use:

	☹				☺	N.A.
Ease of initial learning	☐	☐	☐	☐	☐	☐
Ease of use after learning	☐	☐	☐	☐	☐	☐
Interactivity	☐	☐	☐	☐	☐	☐
Intuitiveness	☐	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐	☐
Precision	☐	☐	☐	☐	☐	☐
Time saving	☐	☐	☐	☐	☐	☐
Quality of shape	☐	☐	☐	☐	☐	☐
Reuse of results	☐	☐	☐	☐	☐	☐

Support for task performance (results achieved as expected/desired)?	☐ ☐ ☐ ☐ ☐ ☐

3. Use of malleable materials

3.1 Type of material you use:

	yes	no	
Clay	☐	☐	
Wood	☐	☐	
Foam material		☐	☐
Other	________		

3.2 Do you use physical prototyping to:

	little … lot
Develop new concepts	☐ ☐ ☐ ☐ ☐
Produce physical models from others' ideas	☐ ☐ ☐ ☐ ☐
Communicate ideas to others	☐ ☐ ☐ ☐ ☐
Detail concepts	☐ ☐ ☐ ☐ ☐

3.3 Evaluate the effectiveness of physical prototyping for:

	☹ … ☺
Develop new concepts	☐ ☐ ☐ ☐ ☐
Produce physical models from others' ideas	☐ ☐ ☐ ☐ ☐
Communicate ideas to others	☐ ☐ ☐ ☐ ☐
Detail concepts	☐ ☐ ☐ ☐ ☐

Questionnaire 2

To complete after using the T’nD system

1. Perceived usefulness

   Testers are asked to rate the usefulness of the system for shape creation, for shape modification and for shape evaluation; to rate the usefulness for designers and/or modelers; to estimate the process benefits and performances; to estimate the perceived improvements of quality of product model; to express the satisfaction with the overall performances of the system, and to judge the possibility to integrate/replace tools and practice currently used with T’nD system.

2. Perceived usability

   Testers are asked to evaluate the easiness to learn using the system, the haptic feel of interaction, graphics/visual feel of interaction, the precision, the quality of shape, the results achieved compared to expected/desired, possibility to exploit users’ skill.

3. Evaluation of physical tool

   Testers are asked to evaluate some aspects of the haptic tools like the ease of learning, the ease of use after learning, the intuitiveness, the precision, the comfort, the d.o.f. of motions, the workspace, etc.

4. Evaluation of visual aspects

   Testers are asked to evaluate visual aspects like correctness of visual definition of surfaces, appearance of visual rendering of surfaces, possibility to evaluate the shape from its rendering, the relation of visual rendering offered by T’nD compared to the one offered by other CAS/CAD tools.

5. Suggestions from users

   - What changes would the user recommend to improve the current system.
   - What new development would the user suggest to improve the current system.
   - What applications and possibilities does the user envision for the use of the system.