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Raw Shaping Form Finding: Tacit Tangible CAD

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ABSTRACT

This paper is aiming at the identification of essential voids in the support of design processes offered by commonly available methods and tools. Some remarkable results were obtained during design sessions with novices and experts by engaging them in tangible experiments that were designed to trigger and enhance their skills, tacit knowing and creativity that enable them to represent their ideas and concepts in an intuitive way. We explored the differences in designer's behavior during use of "analogue" and digital representation tools. We will explain our laboratory experiments, test results, educational embedding and creative opportunities that emerge from hybrid design tools. Furthermore we propose an exciting hybrid design tool to bring back the tacit and tangible elements of design processing into CAD systems.

1   INTRODUCTION

A main task of industrial designers is the shaping and transformation of ideas or fuzzy notions into abstract or tangible abstract equivalents. These representations during ideation or conceptualization can be described as the sum of form and shape aspects, aesthetics, tacit knowledge, intuitive qualities as well as technical and sustainable functionalities. According to Michael Polanyi we should start from the fact that '*we can know more than we can tell'*, he termed this pre-logical phase of knowing as 'tacit knowledge' [15]. Furthermore, Polanyi describes knowing as an active comprehension of the things known, an action that requires skill [16].

The designer must therefore fully understand all the elements involved in this synthesis of representational design processing. To be successful they need to compose, orchestrate, shape and form all characteristics carefully and join them into harmonious and balanced artifacts, while simultaneously steering within implicit and explicit mechanical and functional aspects.

Over the last decades the design industry transformed from a robust traditionally analogue industry to a mere virtual digital one. Design processing speed has dramatically increased and project progression allows us to churn out products at incredible speed. The question arises what substantiated this approach by moving away more and more from the physical domain of designing and subsequently being transformed into tethered followers of programmers' directions or system developers?

There is hardly any physical or material interaction during the early phases of design processing any longer, other than being it from usage of mouse, sketchpad or keyboard interactions. We propose a hybrid tool approach to make up for this lack of tacit tangible interaction and to enable designers to fully benefit from their intuition, idiosyncratic approach, creativity, insight and understanding, and also to allow designers to comprehend their tangible interactions and to experience subsidiary and focal awareness. Our aim is to identify and bridge the voids between the analogue and digital design methods and tools.

2   CURRENT DESIGN PRACTICE

The Designer or Homunculus Intentio (Fig.1) shows design activity, uses design representations to visualize, communicate and express his/her ideas or fuzzy-notions while at the same time sharing these visuals or tangibles with others or oneself. Distributed cognition during the design process enables the designer to manifest ideas to explore and shape product ideas, simultaneously maneuvering within implicit and explicit mechanical and functional aspects, material constraints and aesthetic qualities.

In this apparent design engineering process we place our focus on the ideation and abstract conceptualization phases. We embedded various design assignments in education curriculum, created various haptic and tangible experiments and explored distinctions between analogue and digital representation techniques. Critical issues emerge from designing with analogue and digital tool use, in which the deprivation of sensory perceptions is one of the major ones.

Designers (Homunculus Intentio) are relying on sensory perceptions and sensory feelings, wherein their distortions in visual perception of three-dimensional form can be corrected by tactile observations or tangible interactions.

Fig.1: The Designer with intent.

2.1   Skill, Remediation, Entropy and Emergence

Designers scar, cut, sculpt, ply, fold, score, crease, pinch, pull, push, blow, scissile and engage themselves in visual and tacit interactions with great ease and pleasure! With the emergence of computational design, designers distanced themselves more and more from the physical sensorial perceptions and immersed themselves gladly in virtual digital realities. They were lured into visual poly-dimensional stimulation, worshipping digital virtual realities on high-definition screens, in a make-belief world where the virtual reality became the new orthodoxy.

From this we can deduce that; '…the viewer can pass through the window into the represented world, or the objects of representation can come up to or even through the window and surround the viewer' [02]. This phenomenon has lead to a widening gap between the analogue real and the virtual.

Of course there are signs of hybrid tools augmenting the real and the virtual leading to creative abstractions. The apparent loss of control, manual dexterity and intuitive interactions are leading to increasing inertia and entropy. It is impossible (up to now) being in real sync with a computer or to share some sort of emotional attachment. Most representational technologies deskill, confuse, simplify control, remove the unpredictable, create loss of serendipity and inflict signs of stall and stagnation in processing.

Wooley [24] argues; 'In such we can conclude that emerging digital design technologies are perceived as replacements for traditional skills, and therefore as potentially threatening to deskill novices, journeyman and professionals'. Moreover the designer has is to follow the tailored-system approach, learning and experiencing program procedures and categories until conquering the program threshold by adapting and transforming to it.

McCullough [11] states that: '...We have yet to escape the state where a sensible person can quickly dismiss computer usage for creative work on very simple grounds: one, it's too arbitrary; two, it cannot record feelings; three, you cannot get a hold of it; four, it is difficult and time consuming; and five, it's not much fun.' However, McCullough continues to argue; 'each next generation of technology (far more frequent than generations of human beings) becomes more usable on the basis of faster components, increasing practicality of more intuitive designs, and generally accumulation of technological wisdom.'

In such we can deduce that computing will slowly transform and evolve to become more human. Although McCullough wrote this in 1996 and indeed there have been major advances and improvements in computer interaction and computational design over the last fourteen years, we continue to have an ambivalent relation with computers and computational processing.

2.2 The Best of Both Worlds

Our initial [re]search on these topics was conducted in 2004 by making use of questionnaires about Design Tools and future implications of Virtual Reality in Design Processing. Questions were targeted at student designers, this survey revealed that Virtual Reality is promising only when:

- Tool creates more insight and understanding;
- Tool has low threshold in learning curve(-s);
- Tool increases processing speed in solution space;
- Tool implies visual and tangible representation;
- Tool triggers easy ideation and conceptualizing;
- Tool generates and allows simulation and prototyping;
- Tool allows intuitive un-tethered interaction;
- Tool brings out or emphasizes a skill-set.

The findings and results nudged us towards more [re]search and experimentation in the domain of Virtual Reality, Design Tools and Design Thinking. In a period of five (5) years we implemented several visual and physical abstract representation assignments in the educational curriculum to make observations, measure effectiveness and explore the influence of tacit knowledge and tangible interaction in design processing.

In general one could say that there seems to be a pre-dominance in visual abstract representation over material abstract representation in design education. This could be partially instigated by proximity and abundance of digital technologies within the realm of design education and methodology (Fig. 2).
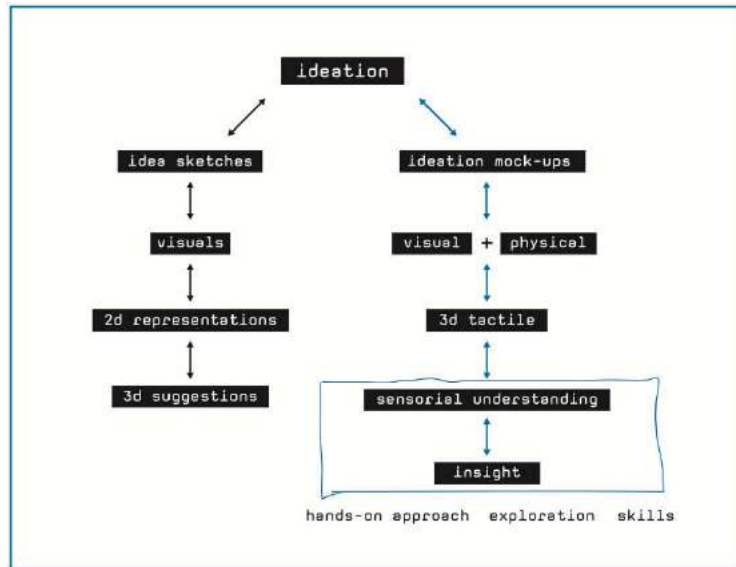
Fig. 2: Ideation with 3D Physical interaction.

Emphasis on sensory perception is by far greater than the implementation of sensory feeling within the design methods. However, learning, experience and knowledge acquisition in design is enabled through continually challenging abstract representations against material representations.

The comparison showed gaps that inspired us to further investigate design processing, design representation and design thinking. In sensory perception we rely on our visual system, tracking, parsing, dodging, spotting, guiding, predicting and sometimes seeing things before they happen. Naturally we have blind-spots that allow us to create visual illusions and allow for disembodiment.

The sense of touch allows us to do more than explore the world around us, it makes us like or loath material sensations. Touch receptors in our skin give us control, power of expectation, creates highly focused attention and physical relaxation (ibid. Mather, 2009). [10]

2.3   Tangible Materials

Sensorial materials isolate defining qualities such as color, weight, shape, form, texture, size, smell, sound, balance, etc. The purpose of these materials is to provide a concrete, realistic, sensorial impression and understanding for abstract concepts. Designers derive and develop basic skills and tacit knowing in the areas of reading and language development, handwriting, mathematics, geometry, geography, cultural geography, biology and science. All these skills have their beginning in sensorial understanding and exploration.

As we know, "The hands are the instrument of the mind" or to paraphrase McCullough, 'Hands are underrated because they are poorly understood' [11]. To work with tangible materials allows the designer to investigate and explore the constraints of materials in all its' splendor. Interaction with materials ignites creative sparks, and the designer's imagination will follow suit. In designing artifacts we can not only rely on our visual system and 'blindly 'accept three-dimensional content on monitors that are part of this illusionary belief system, we need to address and harness the tangible back into design processing. Not only by means of, for example, haptic devices to create some sort of force-feedback and suggests material constraints.

According to Dachille et al. (2001) [05] using force-feedback controls, designers, artists, as well as non-expert users can feel the model representation and modify objects directly, thus enhancing the understanding of objects properties and the overall design. Dachille et al. (2001) states, '…that using haptics in a virtual design environment, designers are able to feel and deform real objects in a natural 3D setting, rather than being restricted to mere 2D projections for input and output.' The word 'natural' being used here is an anomaly in description since it is a virtual 3D synthetic environment.

Furthermore, Dachille et al. (2001) continue to argue that the use of haptics in a virtual design environment promises to increase the bandwidth of information between designers and the synthetic modeling world. We included haptic devices in our experiments to find out if this promise could be substantiated, effective or helpful during design processing.

3   TANGIBLE REPRESENTATION AS PART OF DESIGN TOOLS

The exploration and searching for new design tools through loosely defined projects brought us to further our quest towards humanizing design environments. We devised experimentations in abstract materializing and tangible representation in laboratory set-ups. We embedded creation of artifacts without pre-conceived notions and allowing topsy-turvy design solutions derived from random materials in educational contexts.

In our research we are aiming at identifying voids in commonly available design tools and methods, exploring hybrid solutions integrating emphatic functionality combined with tangible shaping and a mere holistic augmented form finding process. The shaping process as an ephemeral pleasure, ease-in-use, two-handed interaction with free forming capability assisted by ubiquitous computing environment. The concept of ubiquitous 'computing', '…first developed by Mark Weiser et al. is a vision of virtual reality turned inside out. Where virtual reality invites the user to become part of a world beyond mediation, ubiquitous computing offers the user a world in which everything is or contains a computing device' [22].

The hybrid design tool that enables Form Finding through Raw Shaping (RSFF) creates physical models, affords serendipity in shaping, and supports tacit choice-architecture. The 'material resistance' provided by clay, form-sand, aluminum wire, cardboard, or other materials provides a tactile feedback that facilitates some and resists other directions during design processing. Form Finding can be described as Frei Otto [14] has invented and practiced it: using 'reality' modeling to define the problem to one-self, in order to come up with an understanding of a solution. Reality modeling enables the designer to work out the physical consequences from the original concept all the way down to the fine details of the final artifact.

3.1   Tangible Experimentation in Education

Several methods and strategies were devised and used as experiments within teaching and learning contexts, ranging from very abstract-physical assignments to a 5-step design method. The latter has a five phase linear design approach, i.e.: Analysis; Ideation; Idea Execution; Presentation; Representation to design an artefact.

Our latest educational approach is to assign a seemingly more structured method to design an artefact. In this case we hand students an orthogonal projection (Fig. 3, right) of a design icon (Citroën DS) on A4. The elevations are in proportion, but not to specific scale! The first task is to size-change (scaling) the elevation drawings to an exact dimension: 488 x 180 x 147 mm. (Fig.3, left) Many students seem to find this a difficult task and noticeably many variations in size-change become apparent. Some students will take no direct action, contemplating and thinking about their approach.
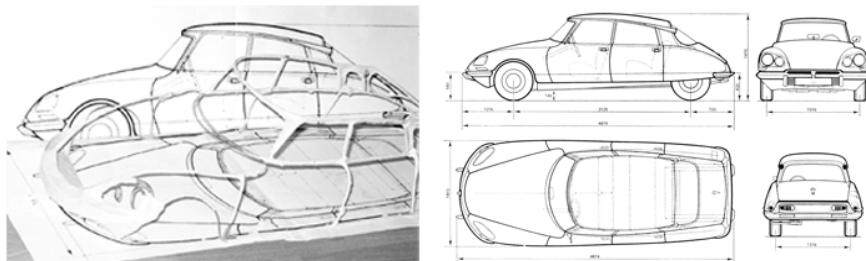

Fig. 3: Size Change (left), Orthogonal Drawing DS (right).

Next they run off to the nearby photocopier to enlarge their drawing. This shows how difficult it can be to get a grip on proportion and dimension. The scaled projections are being used as templates to ply and construct three (3) wire frames (Fig. 4) in aluminium wire, cardboard/paper strips and sheet metal strips. The wire frames have to conform to the enlarged drawings.

Fig. 4: Wire Frame DS (left), Paper Strip Frame (middle), Metal Strip Frame (right).

It is a very complex assignment because of the interpretation and transformation of two-dimensional elevation drawings into three-dimensional wireframe representation. Many questions and issues arise from this design process assignment. Key factors are: Making decisions, being a choice-architect, and confrontation by designing-in-action and thinking-in-action. The final step in this assignment is to add textured surfaces to the wire frame 'inspired by nature' to the wire frame to build shapes of seemingly great complexity (Fig. 5).

The object is to improve insight and to learn how form and shape are explored and created, how a faulty or sloppy production process could do a good deal of harm and entail major implications to the final shape or form-giving of an object (Gilles, 1991) [07]. However, by allowing randomness in design processing, the geometry will be jagged, but with a logic of its own; – one that is easy to understand and which identifies the idiosyncratic value of the object. With the RSFF approach unintentional changes in processing are intrinsic, thus unpredictability in shaping and forming emerges.

Fig. 5: Surface Texture examples on DS wireframes.

3.2   Results Artifact Assignment

Two significant modelling methods emerged after evaluating and analyzing the results of this experimentation: Representation was either done by 3D curves or by slicing.

We based our findings on 36 selected models out of 150 individual iterations made by Bachelor students of Industrial Design. The interpretation and transformation task is devised as a representational form study, finding and discovering aesthetic criteria, triggering aspects of form-giving, tangible shaping and expanding the geometric vocabulary of novice designers.

Our goals are:
- Scaling and Interpreting 2D representation into 3D tangible model,
- Discovering differences in design approaches and form giving methods,

- Finding Form and Aesthetic Criteria in tangible objects,
- Exploring Form Structure that results from Form Organization,
- Enhancing Tacit Knowledge, Understanding and Imagination,
- Creating surfaces on 3D models,
- Stimulating presentation and representation skills by placing real models into virtual contexts.

The selected models were placed in ranking order from best to worst model, where the best being number one (1) and the worst number (36). Our ranking criteria were based on:

- Interpretation of 3D model to the 2D orthogonal projection,
- Scaling and Shaping of 3D model,
- Conforming of 3D model to specified dimensions,
- Proportions and Form Giving of 3D model,
- Amount of detailing in 3D model,
- Overall aesthetics and execution of 3D wire frame and surface model.

The numbering is useful for ranking purposes, analyzing and evaluating the 3D models (Fig. 6).

Fig. 6: 3D Models in order of ranking, top left to right 1, 2, 3,......., 34, 35, 36 (bottom).

Modelling 3D is about relations, proportions and distances between wires, views, surfaces etc. Correct distances between wires give the model the right proportions. The location and positioning of the wires in the frame are dominant aspects in the shape perception. Question arising after studying the models is: to what extend is it easier to interpret proportion and shaping using either Figure 7 or Figure 8? Our hypothesis is that the door lines in Figure 7 cuts the image in three (3) pieces (Fig. 9) that have easier shapes to interpret and are easier to work with in modelling the object. The rear of the car has a triangular shape, the middle part rectangular and the front part translates as a hyperbolic shape.

Without these lines (Fig. 8) the shape is much harder to analyse and interpret, the shape is perceived lower and therefore could be interpreted and transformed proportionally lower in the model.
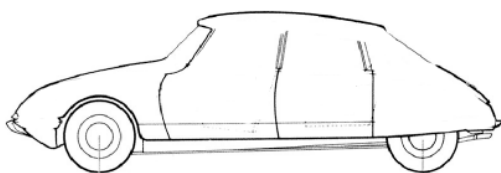
Fig. 7: Sketch with doors.
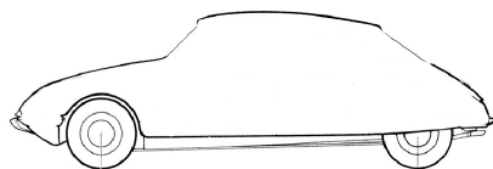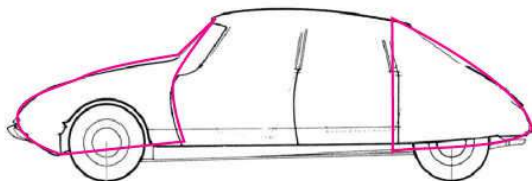
Fig .8: Sketch without doors.

Fig. 9: Door lines cut the image in three parts.

Beyond form and shape, we also took a closer look at the detailing of the models. Figure 11 shows 36 models selected out of 120, with their corresponding levels of detail. Each model shows the lines used for interpretation. We noticed that the more detail lines are used, the better is the resulting 3D model in its various proportions and overall shape. Row 1-6 through 7-12 (Fig. 10 left) show good to reasonable levels of detailing and are characterized by Figure 7, with some explanatory enhancements shown in Figure 9.

The models shown with low or poor levels of detail are typified by Figure 8. We recognize the fact that in some cases the low levels of detail may stem from less motivated or engaged design processing. We also acknowledge the fact that the use of a particular representation heuristic can cause designers to confuse random fluctuations with causal patterns (Fig. 10 right). Often a poor level of detail results in a total lack of proportional understanding, as can be seen in the chart rows 13-18 through 31-36, which represent low to poor levels of detail.

Fig. 10: 3D Model with High-detailing (left), 3D Model with Low-detailing (right).
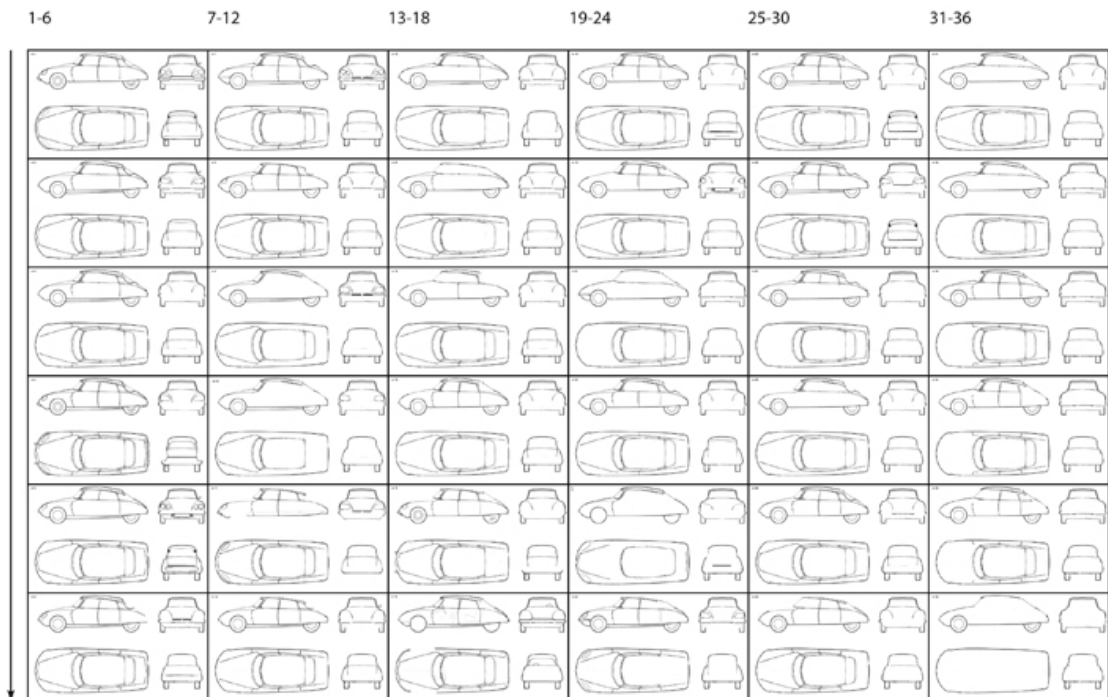

Fig. 11: Models and level of detailing (36 ranked models).

The interpretation of the 2D orthogonal drawings determines the quality of the final model. An incorrect interpretation that occurred frequently is that the central hood line (Fig. 12A - B) is not the same as the fender line (Fig. 12C-D), neither in the drawings, nor on the real model.
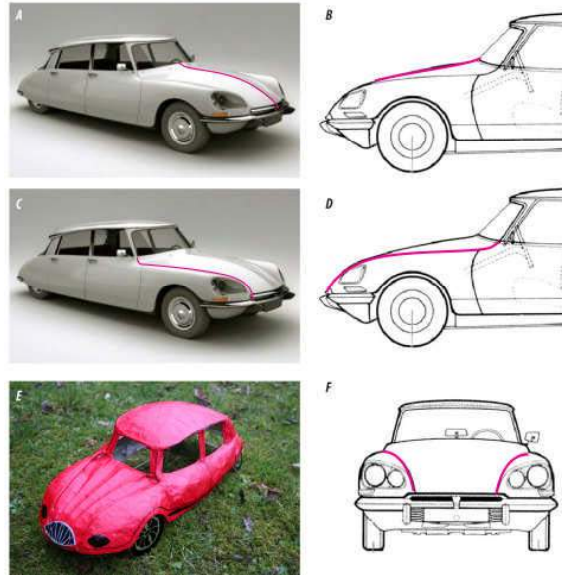

Fig. 12: Modelling and translating curves and lines.

The front and hood are difficult parts in shaping the model, in figure 12 we show the correct corresponding lines to be used in a 3D model interpreting it from the given drawings. Even in the front elevation is it hard to determine which lines should be used for expansion into a 3D model. (Fig. 12F + Fig. 13) The picture of the model in Fig. 12E illustrates what the result is when the expansion is not correctly interpreted making the hood and fender all one piece without the linear separation that is characteristic to this car. This misinterpretation is frequently made during modeling by many students.
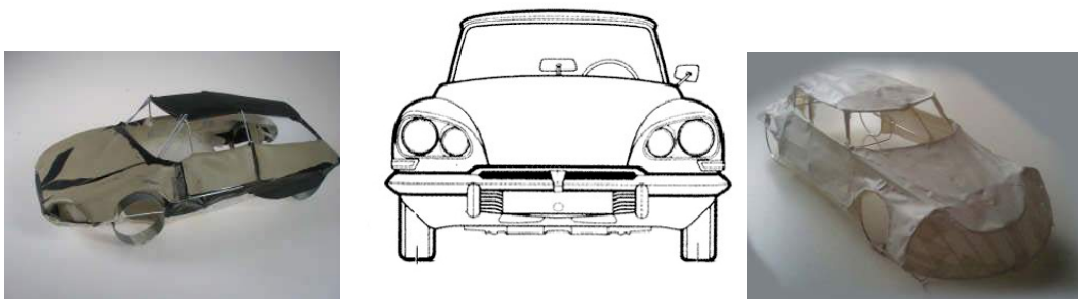

Fig. 13: Frontal view of 2D orthogonal projection (middle), poor detailing (left-right).

In this particular case a tangible 3D model would be helpful to solve this problem during representation, or to incorporate a see-through line in the given orthogonal drawing. Because of this omission in the drawing this aspect is obliterated in virtually every model and transformation.

However, during the execution of the assignment a slideshow of the real car and video footage of the car in action are shown. Furthermore, students have access to one tangible scale model 1:13 as

point of reference. In some cases access to the web is allowed to gather more two-dimensional data on the subject, looking for three-dimensional virtual models is not allowed. We strongly encourage trying to read and interpret the given drawing, use the presented images and video as imagination triggers and looking at the tangible scale model during modelling. We try to evoke and stimulate three-dimensional thinking and triggering insight in spatiality from working with two-dimensional printed and virtual content.

3.3   Two Modeling Methods

We extracted two main methods of modelling the 3D objects from our selected line-up of 36 object iterations. Models were either made by use of the slicing method or through modelling with 3D curved lines.(Fig.14) With the slicing method the respective views from the orthogonal drawings are literally transformed in the model. The top view becomes the base and is often the starting point of the model. All other elevations are 3D expansions of the 2D interpretation and mounted onto the base. The side elevation is being used as a mid section slice in most models (Fig.15).

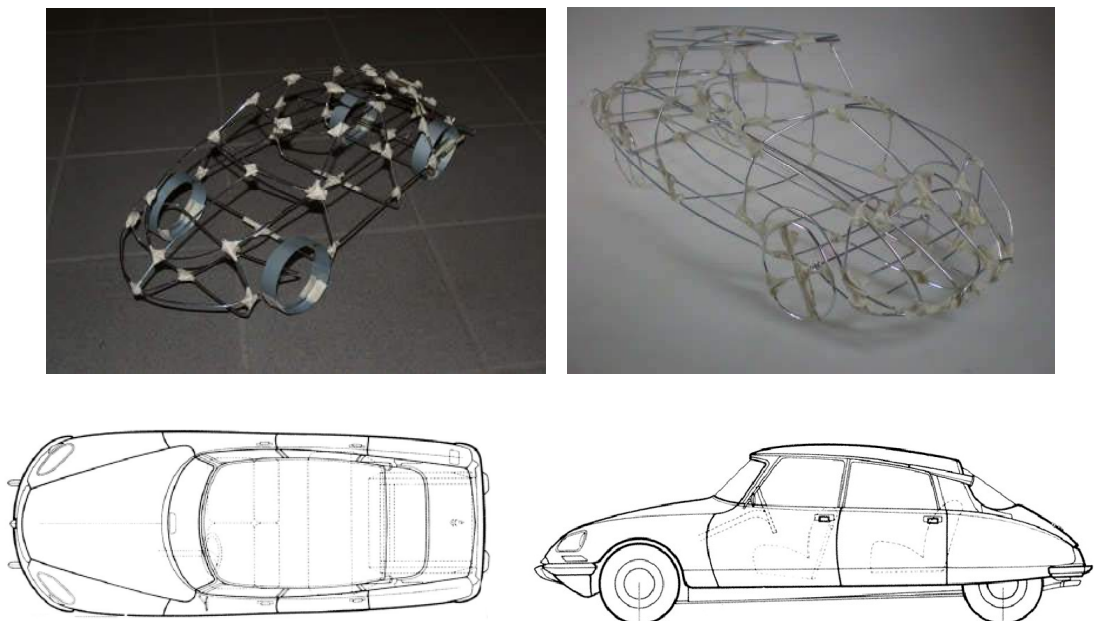Fig. 14: Modelling by slicing method (left), modelling by curves.

Fig. 15: Modelling by slicing method.

The finishing touch of modelling by slicing is the interpretation of the front and rear view to get a good result. Models number 21 through 36 have no rear view transformation in their wire frames, in total 64% did not include this view. Frontal views were not included in 56% of the selected models.

The advantage of working with the slicing method is that you do not require a full three-dimensional understanding of the artefact in advance to start the modelling process. If the designer works consequent and follows precisely the views and elevations from the scaled drawings the result will be accordingly.

Some problems could occur however, the use of double side elevations, the positioning or placement of the sliced section and omitting the expansion of a view or elevation could lead to distortion and extravagance in shape and form. We acknowledge the fact however that this could be part of the idiosyncratic realm of the designer and becomes part of the signature or styling (Fig.16). One side-view should be used in the middle of the model: the location of the specific section or view should be clear: every view should be present in the expansion of the 3D model.

Fig. 16: Double use of side elevation.

When modelling with 3D curved lines the scaled 2D drawings (view and elevations) are being used to create 3D models. The chosen lines for executing the curved line model are not exact outlines or expanded sectional views but flowing and fluent lines in 3D space that cover more than one view or section (Fig.17and 18).
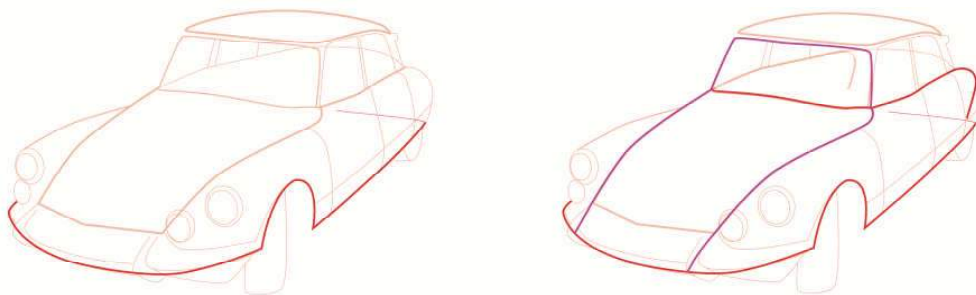

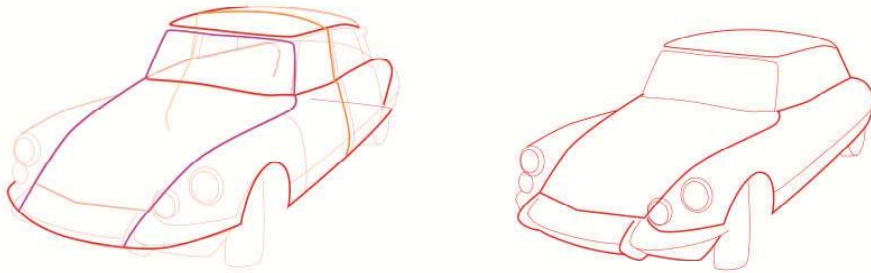Fig. 17: Modeling in 3D curved lines.

Fig. 18: Modeling in 3D curved lines.

The designer has to have a good mental image, detailed insight and understanding of the total shape before commencing with the modeling. (Fig. 19, 20) Since all the views and elevations merge into one or several fluent and curving lines the shape and form should be clear in advance. 'Distortions in the visual perception of three-dimensional form can be corrected by tactile observations' (ibid. W. Gilles, 1991) [04].
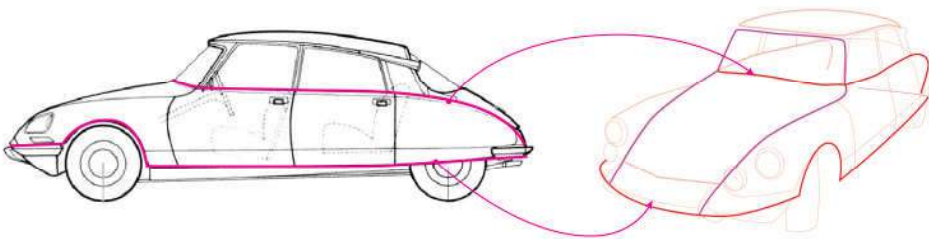

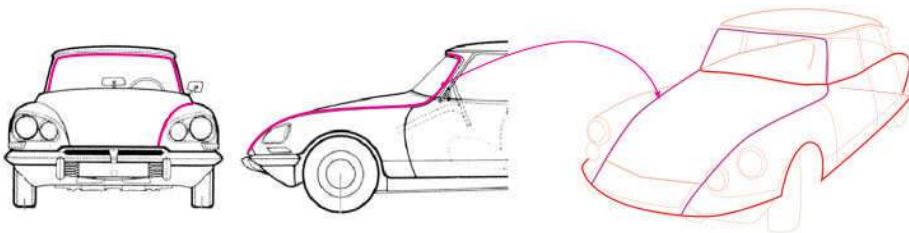Fig. 19: Use of curved lines in car model #01.

Fig. 20: Use of curved lines in car model #01.

Understanding curved lines in 3D space and being able to make an expansion into a 3D tangible model is an individual skill based on tacit knowing and interpretation talent for spatiality (Fig.21). Multi-dimensional insight and the ability to create 3D models of exact proportions and shape is what we need to address in design education. This can be helped by providing more tangible representations during ideation and conceptualization. Creating understanding and insight through manipulation, in the forming of tangible wire frames is beneficial even as training for future work with 3D CAD tools. In most cases, and quite visible in our selection, few students were able to use solely the curved method. Most of them used the slicing method. Numerous students used hybrid version of both methods, with the hybrid models as idiosyncratic results (Fig. 22).
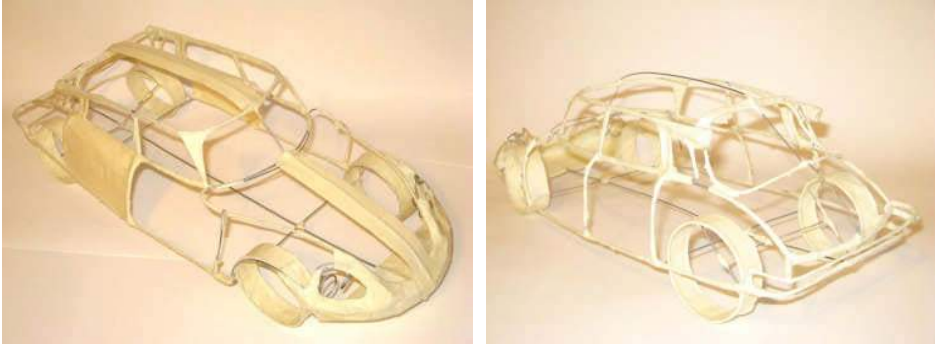
Fig. 21: 3DModeling with curved lines car model #01.

Fig. 22: 3DModeling with hybrid methods.

3.3   Experimentation with Tangible Haptic Tools

We were not surprised, but intrigued, to see the enormous discrepancies and variations in form, shape, design, proportions, and textures of the models, and in the creations of idiosyncratic artefacts. The emergence of the huge variety in possible design solutions shows the phenomenal untapped potential of learning-by-doing, thinking-on-your-feet, and knowing-in-action.

In our observations and while analyzing the results we concluded that if we allow randomness, ambiguity and creative tinkering during the design process, then student designers become better synthesizers. The combination of tacit knowing and tangible modelling as parallel congruous interactions, gave way to enhanced results and to more insight and understanding, while at the same evoking awareness, passion, self-esteem, sense-of-ownership, value and confidence.

3.4   Seven (7) Representational Design Experiments

We introduce seven haptic representational configurations and set-ups for testing purposes. The participants are given an orthogonal projection of an artifact, a perspective template enforcing a size constraint (Fig. 23) and a specific design tool. After a brief set of instructions they are asked to make some kind of 2D sketch, 3D model or rendering thereof with the particular tool provided. For all these tests, there is a five (5) minute time limit, unless otherwise stated.

Fig. 23: Perspective template and maximum size constraint.

The aim of the experimentations is to measure, explore and quantify the effectiveness of un-tethered and tethered tool use, apparent routines, mediation of restraints, signs of flow and stall, as well as gestural and skill development. The following benches were used in our research laboratory:

Fig. 24: Pencil Sketch Bench (l), Sand Sketching Bench (c), Steam Sketching Bench (r).

Pencil-, Sand- and Steam sketch test benches are based on free-hand sketching, tacit knowledge and intuitive interaction. The participant has to create a 3D perspective drawing of an artifact starting from an orthogonal projection of it. To test the methodology in these set-ups, we measure effectiveness, ideation skills, visualization speed, apparent tacit knowing and the threshold in learning. The data captured by video cameras will be analyzed and evaluated in conjunction with other datasets from other experiments (Fig. 24 left).

During Sand sketching the processing becomes 'hindered' by the randomly moving sand kernels. This encourages faster iteration and intuitive interaction (Fig. 24 mid).

During the Steam sketching sequence participants are prompted almost immediately into speedy interaction to create their drawings on the fogged-up mirror. This test set-up demands speed because of the constant flow of steam over the mirrored surface. The sketches become almost invisible soon after sketching. Thus they stimulate action, fast performance and inspire flow-in-action (Fig. 24 right).

Fig. 25: Sculpting Bench (l), Wire Plying Bench (r).

The two-handed Sculpting test bench maximizes the tangible experience of the participant. The formable mass (form-sand) allows for fast and speedy iterations and stimulates the senses and imagination. Some wooden tools are being used during processing to allow the introduction of some detailing (Fig. 25 left).

The Wire Plying test bench is based on two-handed interaction and free form plying in aluminum wire. The participant has to create a 3D wire frame of an artifact shown in a set of orthogonal drawings. The use of tape, pliers and wire cutters is allowed. The transformation of the 2D projections into 3D tangible wire frames brings out tacit knowing and enhances skill, touch, and choice architecture (Fig. 25 right).
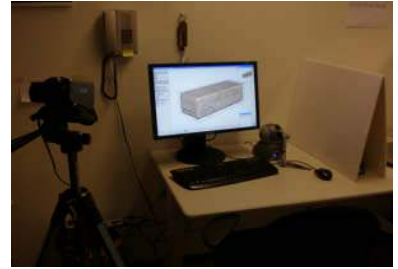

Fig. 26: Solid Works Bench (l), Virtual Clay Bench with haptic force-feedback device (r).

The next two sets of experiments are based on digital representation tools. In the first procedure we engage the participant in 3D CAD sketching using Solid Works. To lower the threshold in learning we provide a three-dimensional workspace including views and elevations of the artifact. The participant has to create a 3D virtual representation of the artifact using the CAD tool and its interaction device (mouse). In most cases we allowed more time than the standard 5 minutes of the other tests to allow the user to become familiar with this virtual design tool (Fig. 26 left).

The last test bench we is based on 'Virtual Clay' in combination with a haptic force-feedback device. After a brief set of instructions the participant had to make a 3D virtual clay model from the given 2D projections. We provided a block shape of virtual clay including views and elevations of the artifact to lower the learning threshold and to allow the participant to concentrate directly on the task (Fig. 26 right).

Again we had to allow for more time (see chart Fig. 27) because of difficulties with the tool, the high learning threshold, or sensory perception problems when working with the haptic device.

4   ANALYSIS METHOD AND RESULTS

We used Video Interaction Analysis (VIA) (Jordan & Henderson, 1995) [09] to investigate the gestures, expressions, actions, immediacy (context), iterations and interactions with hardware and software. Video recording enables us to make qualitative evaluations of the various tests. Data was extracted from the video footage from the various test benches.

We assessed 208 participant tests by students and experts. We videotaped 27 hours of interaction during a 3 months period, which resulted in a great amount of data. All the participants were made aware of the video recording but no further reference was made to the video camera during the assessments. Since we engage in ongoing experimental research, we decided for this paper to use a quantitative selection of 83 participants (Fig. 27) and drew provisional conclusions from the selected raw data.

	pencil	sand	steam	sculpting	plying	3d solid	virt.clay
number of participants	25	38	40	34	28	22	21
total high speed video test time edited [mm:ss]	26:00	16:00	20:00	25:00	24:00	34:00	46:00
real total video test time [h:mm:ss]	3:28:00	2:08:00	2:40:00	3:20:00	3:12:00	4:32:00	6:08:00
average test time per participant [mm:ss]	08:19	03:22	04:00	05:53	06:51	12:22	17:31

Fig. 27: Mapping + Result Chart VIA (selection).

The on-the-fly ideation of a design task and representing it either abstractly or tangibly showed us that a haptic interface is very useful. Results show us that tangible interaction has merit, speeds up interaction, lowers threshold in learning curve and stimulates flow and engagement.

Un-tethered two-handed interaction is adding more quality, more detail, and it conveys higher end-output. Less demanding interfaces steam up the pace and create flow in interaction. The force feedback from physical materials enhances concentration and involvement in the design task.

The use of digital devices (i.e. mouse, keyboard) and the use a force-feedback device in ideation and conceptualization did not prove to be very effective. In some cases the participants gave up or became frustrated with their results showing on the screen.

We observed the same duality in the results and representations as we did with the tangible experiments in an educational context. Every method has its own specific interaction, use of physical manipulation, tacit knowing and idiosyncratic progression. By setting tight time limits we were able to speed up choice-making during processing, which resulting in a larger variety of qualitative results. In our preliminary analysis and evaluation of the results we concluded that even though the given task was the same for all participants, they all executed their ideas and notions based on their individual skills, insight, understanding and tacit knowing.

From these preliminary findings we constructed a conceptual framework for interaction design that incorporates tacit tangible interaction. With this we plan to explore the possibilities of creating an intuitive product design tool. The following selections show the tangible and virtual results of the various test benches (Fig. 28–34).
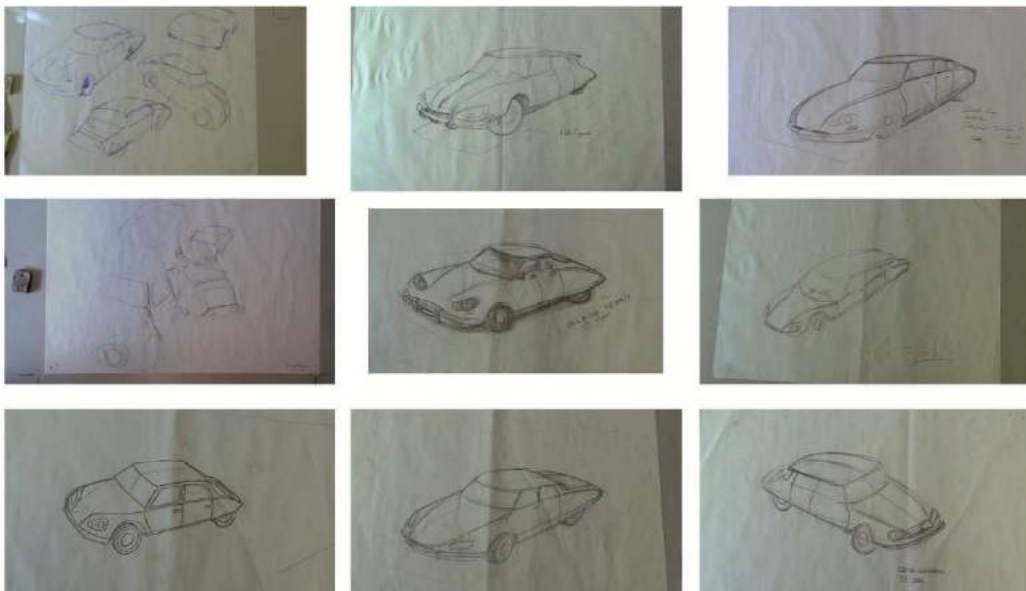

Fig. 28: Result Pencil Sketching-bench (selection).

Fig. 29: Result Sand Sketching-bench (selection).

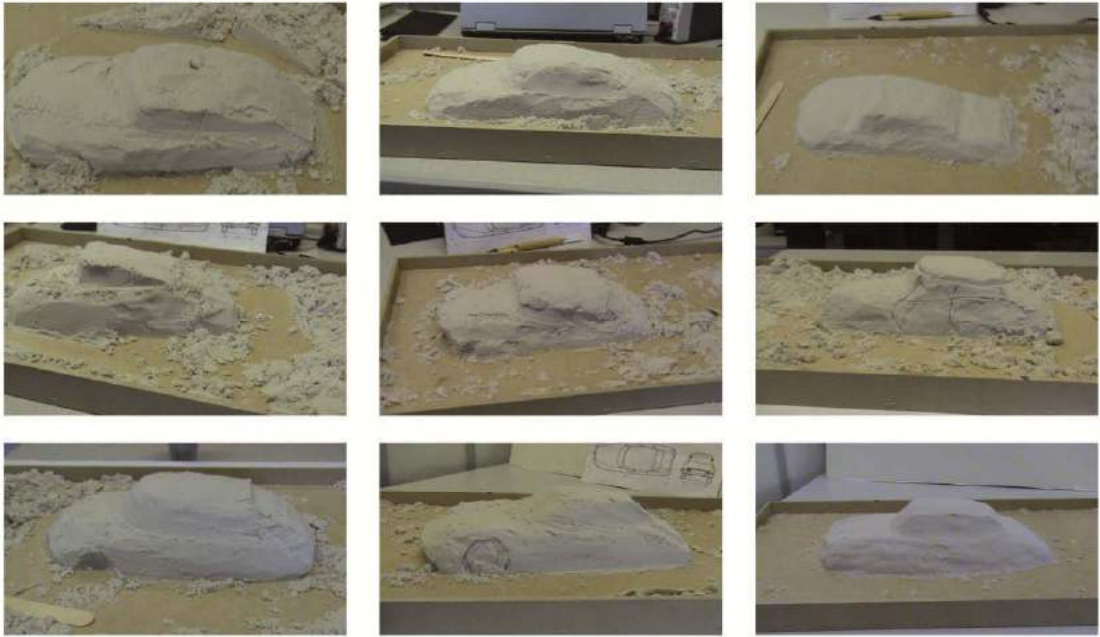Fig. 30: Result Steam Sketching-bench (selection).

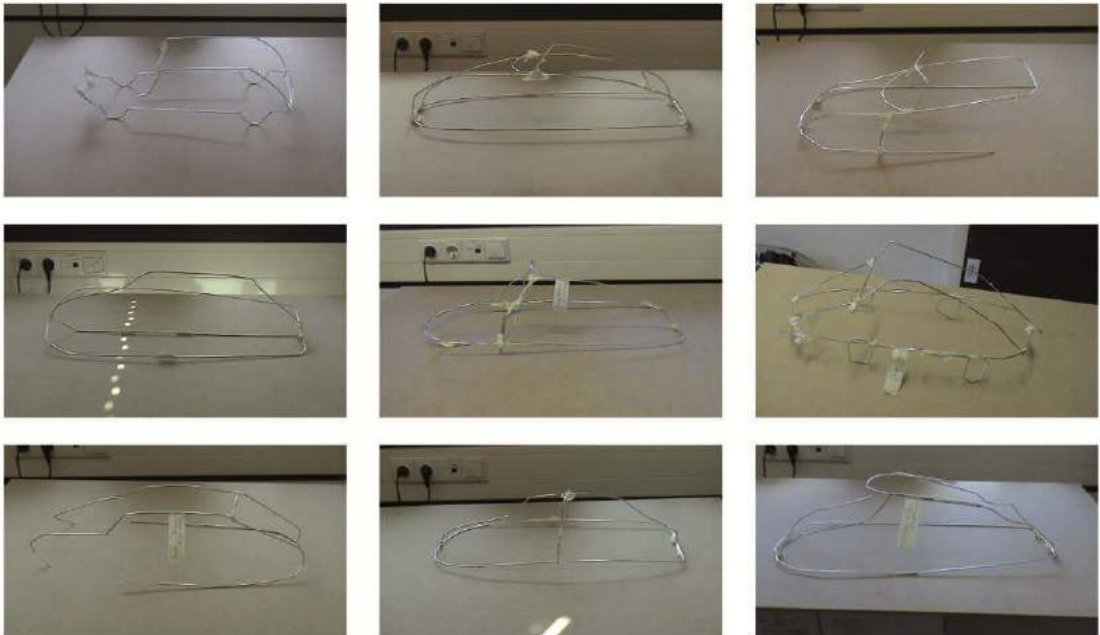Fig. 31: Result Sculpting-bench (selection).

Fig. 32: Result Wire –Plying bench (selection).

Fig. 33: Result Solid Work bench (selection).

Fig. 34: Result Virtual Clay bench (selection).

5   TOWARDS TACIT TANGIBLE CAD SYSTEMS

We set out to combine all our gathered data, [re]search findings and explorations to devise a system that hands-back control to the designer, without substituting or replacing the computer! We now consider the computer as an assistant to support our tinkering, modeling and design processing.

We use our conceptual interaction framework, including data from our technology scan (Fig. 35), for analyzing tangible interactions as a function of a few of parameter dimensions, trying to create insight and understanding of the different levels of abstractions, and the similarities and differences between the physical and digital modelling activities.

This framework enables us to explore various aspects in the user interaction domain, user intuition, device and tool functionalities. It also allows us to investigate emerging program directions for future CAD systems. The preliminary results and datasets from our experimentation procedures show that with respect to ideation and conceptualization, tacit and tangible iterations are easier, more direct, faster and more intuitive than commonly available tools or methods.

During ideation or creation of concept the ability to create, to imagine and to associate freely with abstract or tangible materials are considered crucial factors for an effective design process. Bringing back tangible interactions, and allowing tacit knowing and designer skills to emerge, will lead to more creative output in a shorter time span. The Virtual Design Assistant (VDA) (Fig. 39, 42 a-i) stores the captured iterations as polygon meshes (listing) by mimicking the tangible representations, and storing them in a database as time-stamped snapshots. By creating such a timeline of the evolving tangible object manipulations captured by means of a vision system, the hybrid tool allows the fusion of different polygon meshes with subsequent optimization.

The RSFF design process chart indicates how the active and passive interactions are embedded in the hybrid design tool (Fig.36). We believe that such a tool will be a valuable addition to the panoply of current design tools and methods.
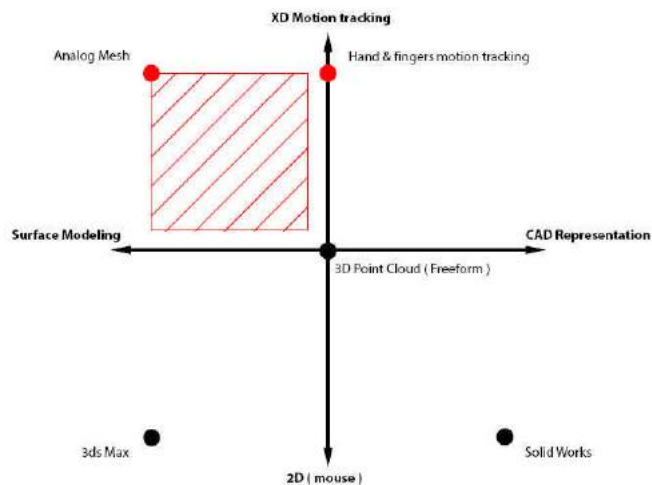

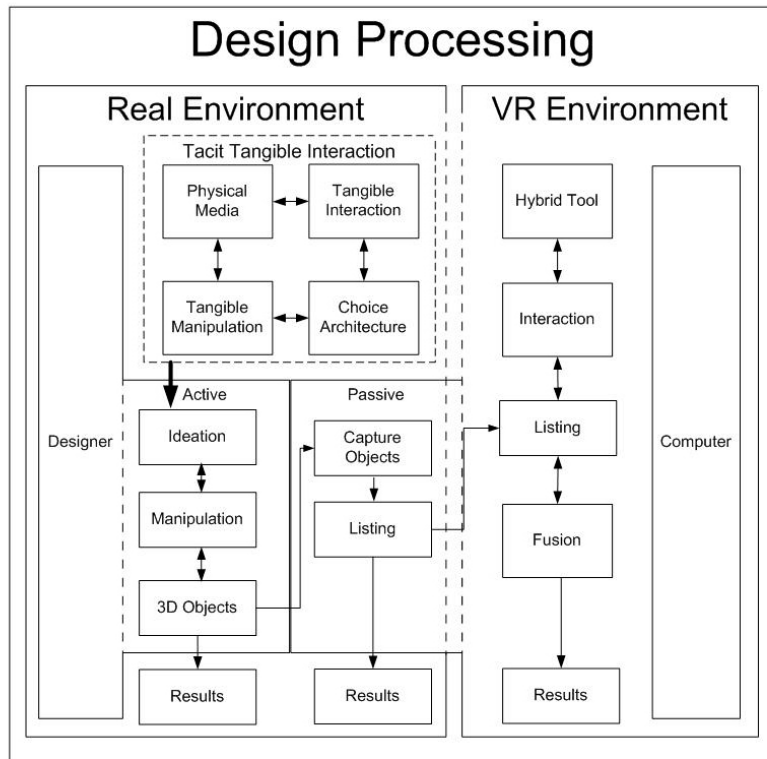Fig. 35: Research framework comparing various CAD design interaction tools.

Fig. 36: Design processing using physical and digital representation as envisioned in Raw Shaping Form Finding (RSFF © 2008) [18].

5.1 The Tangible Workbench and Virtual Design Assistant

We propose a new method of design conceptualization and ideation based on intuitive skills, tacit knowing, reflective praxis and tangible augmented representation. The method entails the creation and development of a two-handed material representation Workbench with real-time or near-real-time vision-based components that generate polygon-mesh iterations as possible design solutions (Fig. 37).

Fig. 37: Two-handed interaction (left); virtual model from tangible interaction (middle); VR model with example of a polygon mesh (right).
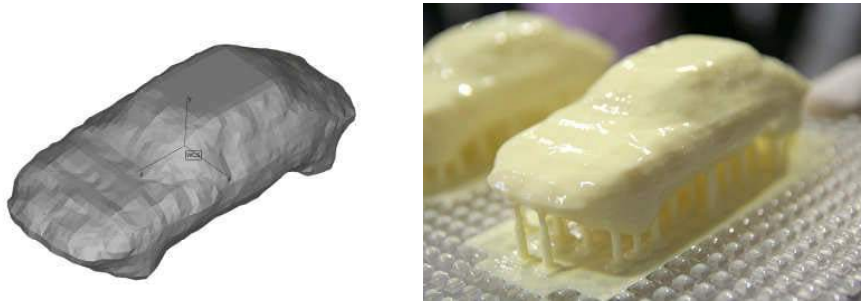
Fig. 38: STL model from VR model (left), 3D multi-layered manufacturing model.

The Virtual Design Assistant (VDA) is conceived to also interact with the subsequent phases in engineering an actual product. There is the possibility to insert raw functional elements (i.e. mechanical parts or printed circuit boards) into the mesh iterations, or to fit the emerging shape to the functional and technical requirements with the use of appropriate simulators. The generated meshes can also readily be exported to produce tangible models with multi-layered manufacturing (Fig.38).
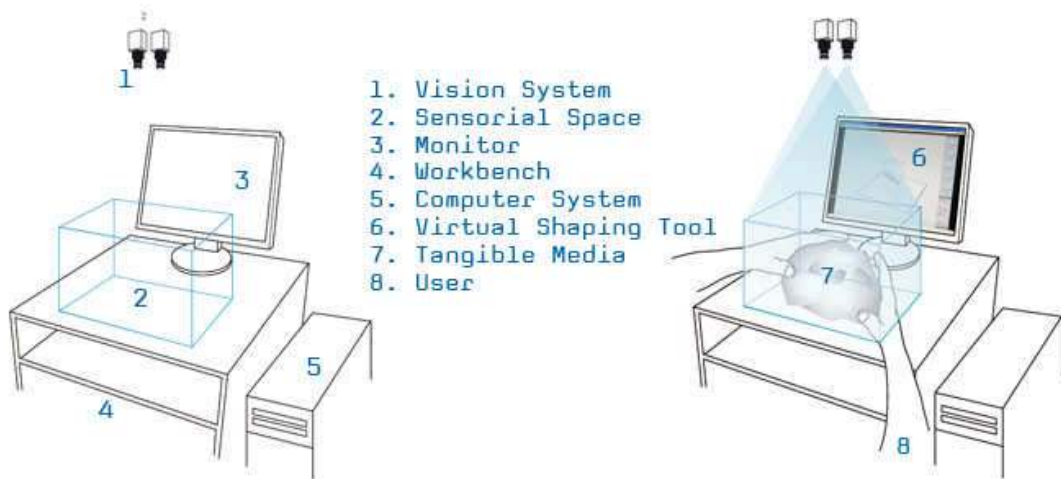

Fig. 39: Set-up Workbench and Virtual Design Assistant.

5.2 Explaining the Prototype Hybrid Tool

We designed and created a prototype of a two-handed physical representation Workbench (Fig.40) with vision-based components that capture the iterations during design processing. The designer standing at the Workbench is tinkering, thinking and designing physically, processing ideas with tangible materials to shape and form possible solutions. (Fig. 39-7, 39-8, 41)

Various stages of the design evolution are captured as raw polygon meshes (Fig. 39-6, 42). They are also stored in a database that is shown as a listing (history) and is also directly visible on the monitor in a separate solution space window.

Fig. 40: The Workbench.

Fig. 41: The designer engaged in physical interaction.

There is no need to look at the monitor during the execution of the design task. The designer is un-tethered and can freely manipulate materials, create various physical models and concentrate on the work. The RSFF-method creates room for re-shaping, styling and applying geometrical corrections with other CAD tools while at the same time leaving the idiosyncratic mark of the designer.

a   b   c

d   e   f

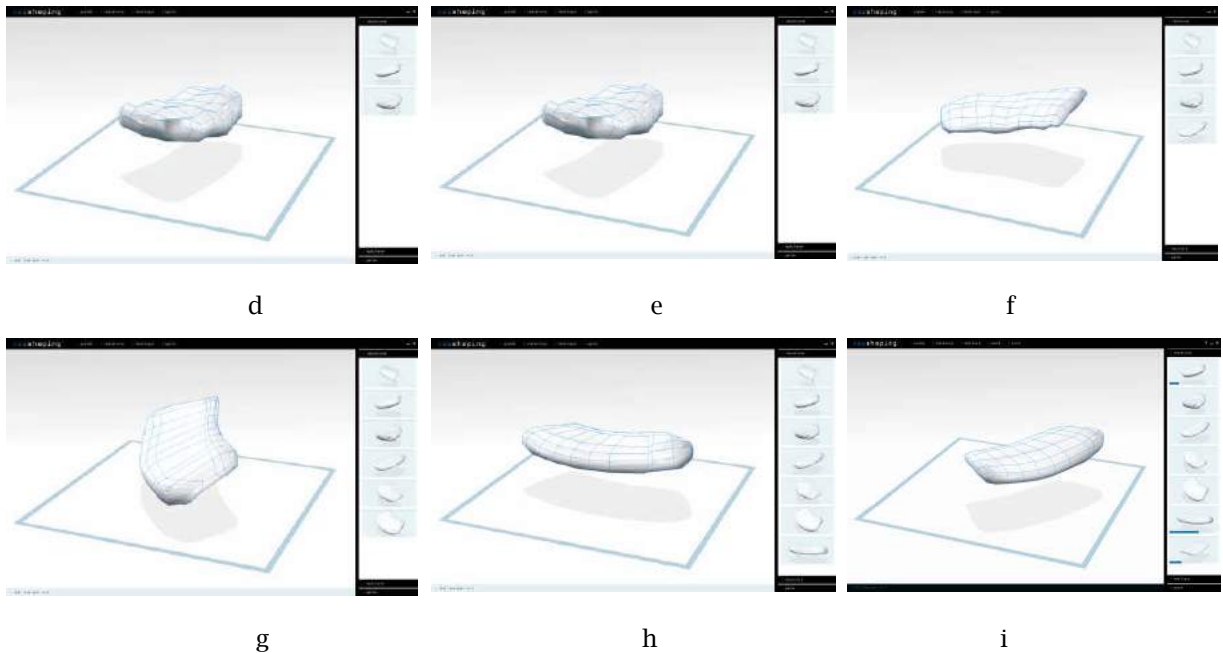g   h   i
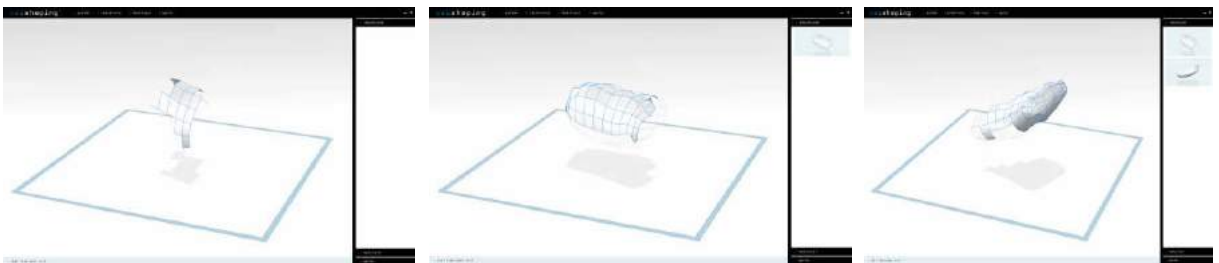
Fig. 42: A sequence of an evolving design (a-i) on the Virtual Design Assistant (VDA).

When the designer decides that sufficient tangible results have been generated and the outcome of the design processing is deemed satisfactory, the hybrid tool will be used in a new mode. The stored shapes (poly-meshes) are reviewed and ranked as to which of them fit the requirements (Fig. 42 a-i) They can then be combined and used to synthesize novel and more refined solutions (Fig. 44).

Again, the designer is in control of this choice-architecture. To enable this interaction, the system incorporates a multi-touch screen to support the designer during this step in the process. (Fig. 43)

The suggested feeling of real touch stems from virtually touching on screen 'your shape' or 'product form' and augments the real with the virtual environment. It reconnects the designer with the virtual artifact and reinforces the feeling of engagement. Besides it could stimulate enjoyment to work with synthesized design environments.

To hand the designer the feeling of control over his virtual shape by means of on-screen two-handed interaction the engagement with the virtual artifact becomes hyper-mediated. Hyper-mediation suggests in this context, not so much "being immersed" as "being interrelated or feeling connected" (ibid. Bolter and Grusin, 2000) [02].

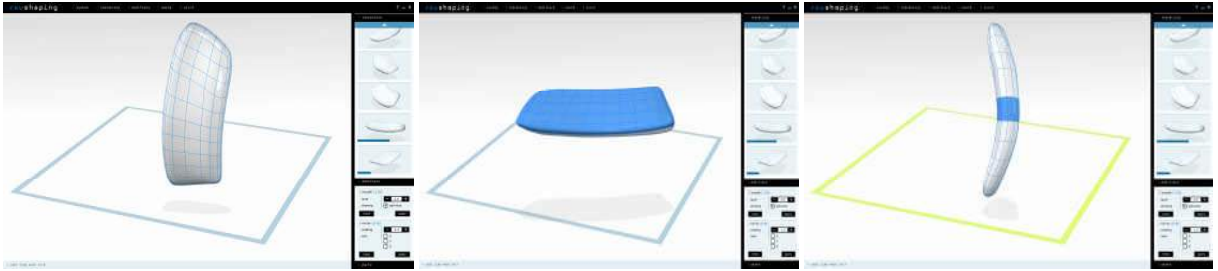Fig. 43: Interaction with the Hybrid Design Tool.

Fig. 44: Virtual shaping tool in action – polygon mesh iterations.

The polygon-mesh iterations can also be used in cyberspace through Virtual Design Gaming between designers or design teams. For example, having VDA's on different locations with designers sharing multiple mesh iterations and engaging in conceptualization contests could bring out interesting possibilities.

6   SUMMARY AND CONCLUSION

We should start from the fact that '*we can know more than we can tell*'. Michael Polanyi termed this pre-logical phase of knowing as 'tacit knowledge'. Tacit knowledge comprises a range of conceptual and sensory information and images that can be brought to bear in an attempt to make sense of something. The designer is filled with a compelling sense of responsibility for the pursuit of a hidden truth, which demands his services for revealing it. His act of knowing exercises a personal judgment in relating evidence to an external reality, an aspect of which he is seeking to apprehend. (Polanyi, 1966)[15] 'Abstract conceptualization now becomes something one can analyze and work from'. (Finger and Asún, 2000), [06].

In Donald Schön's, *The Reflective Practitioner* (1983) he directs his attention to technical-rationality as a positivist epistemology of practice [19]. According to Donald Schön it is 'the dominant paradigm which has failed to resolve the dilemma of rigor versus relevance confronting professionals'. The notions of reflection-in-action, and reflection-on-action were central to his research efforts in this area. The former is sometimes described as 'thinking on our feet'. It involves looking to our experiences, connecting with our feelings, and attending to our theories in use. It entails building new understandings to inform our actions in the situation that is unfolding. The 'practitioner-designer' allows himself to experience surprise, engage in puzzlement, allows for faltering or confusion in a situation which he finds uncertain or unique. He reflects on the phenomenon before him and on the prior understandings which have been implicit in behavior. He carries out an experiment or interaction which serves to generate both a new understanding of the phenomenon and a change in the situation. (Schön, 1983) [19].

We find that our educational experimentations, design method and system could provide a useful platform for the development of new and more sophisticated design representation tools. Our aim is to bridge the voids between the physical and the virtual worlds by making use of tacit skills and traditional tools. An intuitive augmented workbench and common sense provided us with a huge amount of data and information on design processing. The findings and results of our fundamental research in the educational field and laboratory tests show that intuitive physical raw shaping and form finding are instrumental in the creation of understanding and insight, while performing a design task. The design process in the ideation phase will be enhanced and improved significantly through the assistance of a virtual computational device.

We continue working on synthetic computer environments that will enhance the designers' seeing-drawing-feeling-sculpting activities, and extend the repertoires of physical and virtual prototypes. Our goal is to create an environment that helps the designer to discover and reflect upon his/her own design knowledge and experience, while simultaneously sharing this know-how and experience with other designers or stakeholders.

Our approach to create a Virtual Design Assistant (VDA) recognizes the importance of computational design as well as the idiosyncrasies of designers and tries to pair them with, rather

than to confront them with the digital modelling constraints and perceived affordances (ibid. HCI, D. Norman, 1988) [12] [13].

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