INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

EVALUATION OF CLAY MODELLING AND SURFACING CYCLES FROM DESIGNERS PERSPECTIVE

Chandra, Sushil
Hero Motocorp Limited, India

Abstract

A good example of the manual vs. digital divide in design process is the studio modelling process. On one hand, the manual clay modelling offers the much needed tangibility and adds a touch-and-feel quality, whereas the digital clay offers flexibility and accuracy. This paper attempts to (a) analyze various options covering the manual to digital spectrum (b) devise a scientific criterion to evaluate them and (c) conclude the best option. After calculating weighted quality level for each function the results showed that overall value addition is best in digital route due to the head-start it gets in the first step, where 3D sketching provides the best advantage in terms of detection and quantification. In subsequent stages, the manual-digital route adds best values, due to the mix of qualities of digital and forward routes. This results in a hybrid option (3D sketch to virtual reality to hard clay) which offers the best value addition. A dispassionate evaluation of all options is needed to get the best mix of new and traditional and this study has attempted to objectively explore the best mix of digital and tangible processes to optimally exploit the advantages of all processes.

Keywords: Product modelling, Conceptual design, Computer aided design (CAD)

Contact:
Dr. Sushil Chandra
Hero Motocorp Limited
Research and Development
India
sushil.chandra@hotmail.com

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Today the design process is trapped between two divides- emotional vs. functional and manual vs. digital. The most glaring example of the manual vs. digital divide is the studio modelling process, which is in a fluid state today. On one hand, the manual clay modelling offers the much needed tangibility and adds a touch-and-feel quality. The digital clay, on the other hand, offers the benefits of flexibility, accuracy and time. Though radical design thinkers like Rovenna Reid have tried to 3-dimensionalise the design process from the start itself (Hannah, where the designers start with exploring with real hard objects in 3-D, traditionally the design process starts with sketches getting 3-dimensionalized in form of hard clay model and is finally consolidated through surface model in CAD. This means that though the digital age has been able to make the whole process much more efficient, the process essentially remains manual, so far as the creative inputs are concerned. Sure, virtual clay modeling using a virtual hand (Fujiki et al, 2000) and algorithms for creating complex surfaces through virtual modelling (Kai et al, 2010) and human computer interaction in particular context of clay modelling (Hummels et al, 1998) have been suggested, they are essentially variations of the manual process for the stylist. In fact to resolve these issues and find an optimum solution a project called FIORES ('Formulation and Integration of an Optimized Reverse Engineering Workflow') was started by a consortium of 12 partners from 6 countries in Europe and as a result we are having refined algorithms to achieve high quality surfaces from reverse engineering.

2 OBJECTIVE

To harness the advantages of both, digital and manual processes, hybrid models have been suggested where a rough physical model is made from a rough computer model and then the captured data is refined on computer. (Aoyama and Nishizawa, 2000) Going beyond subjectivities, this paper attempts to (a) look at various options available with the designers covering the two extremes of the manual to digital spectrum (b) devise a scientific criterion to evaluate these options and (c) conclude the options with the most benefits.

3 REVIEW OF PROCESSES

The currently available processes and options are as shown in Tables 1 and 2. The processes in digital styling are shown in Figure 1.

Table 1. Styling Cycles

Reverse	Sketch- clay model- scanned Surface- detailing
Forward	Sketch- surface- milled clay model- detailing
Hybrid	Sketch- surface- modified milled clay model-scanned surface- detailing

Table 2. Processes in Digital and Manual Styling Cycles

Stage	Manual	Digital
Sketch	2D sketch	3D sketch
Clay	Clay modelling	Virtual reality
Surfacing	Scanned data surfacing	Surfacing from 3D sketch

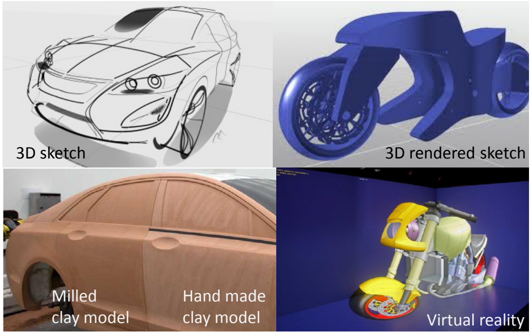


Figure 1. Processes in Digital Styling

In order to evaluate the various options to maximize advantage, a mix of manual and digital processes as being practiced today in industry gives following options (Figure 2):

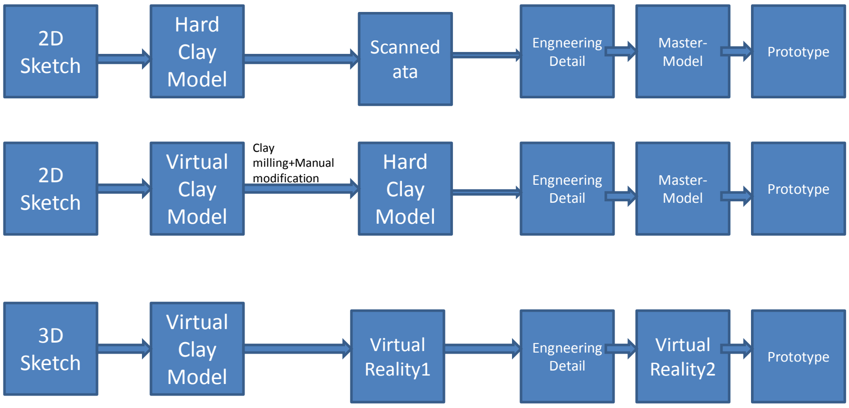


Figure 2. Styling Options for Process Mix

Before we discuss the methodology, it is important to understand the three terms- (1) Styling functions (2) Styling parameters and (3) Process Quality Elements.

3.1 Styling Functions

Krippendorf (2006) assigns two types of meanings that a designer assigns to an artifact- meanings in use (or functional) and meaning in language (or emotional). Moreover the shape grammar to maintain the brand identity has to evolve while maintaining the fundamentals of the grammar (McCormack et al, 2004) Considering the two types of meanings along with the shape grammar and deconstructing them into fundamental factors (here we are considering automobile design as reference), we get the following styling functions which must be fulfilled by a clay model: form, colour, unity, dynamism, reflection, ergonomics, aerodynamics and manufacturability.

3.2 Styling Parameters

Various styling parameters determine a clay modeled surface and the character of a surface can be optimized by varying these parameters (Gianini et al, 2004). Moreover the clay model (manual or virtual) can be optimized by addition, deletion or change of free-form features or parameters (Fontana et al, 1999). The predominant among these parameters are described in the following figure (Figure 3):

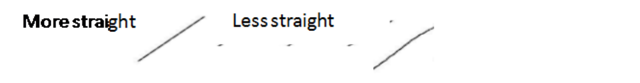
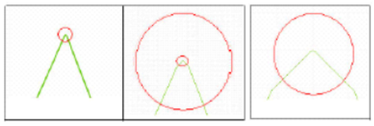
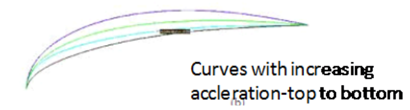
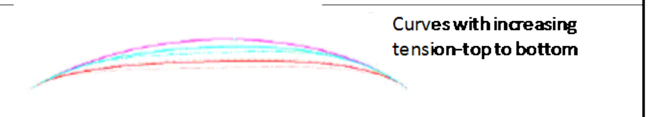
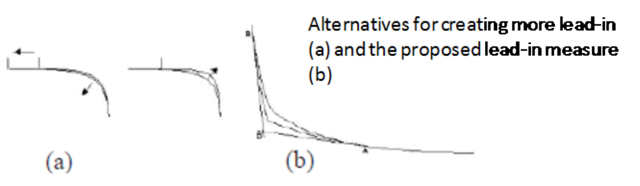
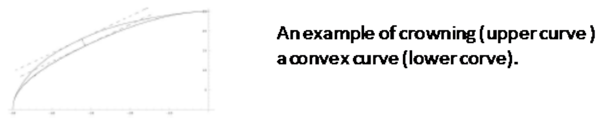
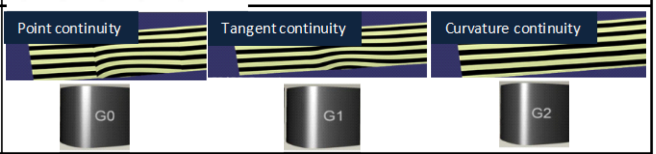
Radius	For stylists, radius is the rounded transition between two surfaces and the factors which make it define the character of a design are its sharpness, its uniformity, the continuity level and its seamlessness	
Straightness	Unlike geometry, in styling, lines are more straight or less straight. It is an important indicator of the surface quality.	
Softness/sharpness	Large angle and large radius result in a soft surface whereas small radius and small spread angle result in a sharp surface. Sharpness or soft define the character of a surface.	
Space	convex and concave (hollow) shapes are known as spaces by stylists. The extent of convexity on concavity or the type of their combinations predominantly decide the character of a design.	
Acceleration	Acceleration of a curve or a surface isdefined as the rate of change of curvature. This is an important indicator of design intent.	
Tension	Tension of a curve mean something happenibg to the curve. This means it is a measure of evolution of a curve. This is largely applied to relatively straighter portions of asurface	
Lead-in	This is an indication as to how abruptly two surfaces merge. The meeting of two surfaces through a constant radius is the elementary level of lead-in. where a good lead-in occurs where the blending curve is smoothly lead into the radius to look harmonic. In short, the lead in prepares the eye for what follows.	
Crown	Crowning of a curvature means adding material in the model to change the cuvature characteristics . In short it a measure of convexity of a surface.	
Continuity	For stylists, it defines the class of surface, which depends on the degree of surface curvature and typeof contuity, G0 (position continuity),G1(tangent continuity), G2 and G3 (curvature continuity)	

Figure 3. Styling Parameters

3.3 Process Quality Elements

The overall quality of a modeled surface is the result of a cycle consisting of a forward branch of shape creation, deformation and criterion input, the comparison with the targeted parameters and a feedback branch of modifying the deformations (Bosinco et al, 1998). Thus the value adding capability of a process depends on four criterions:

a. Detection: This indicates the capability of a process as to how effectively an evaluator or designer can detect the styling parameters. This includes touch and feel capability, magnification and other features that help a designer to detect a parameter or a flaw.

b. Quantification: This is the capability of a process to offer quantified parameters.

c. Correction: This indicates as to what extent and how well the designer is able to correct the surfaces based on the feedback received through detection and quantification.

d. Verification: If the designer is able to verify the result and the quality of correction, the process is supposed to have good verification capability.

4 METHODOLOGY

The basic approach of this evaluation has been adopted from House of Quality matrix (Tapke et al, 1997) where voice of customer and engineering descriptors have been replaced by styling functions and styling parameters respectively and technical correlation matrix is replaced by interrelationship matrix shown in table-5..

Relationship matrix: This denotes the relationship indices between styling functions and styling parameters. Relationship index is denoted by ‘r’ and is measured on a scale of 0 – 3 where:

0: No relationship; 1: Remote and indirect relationship; 2: Direct but not very strong relationship; 3: Strong and direct relationship

The matrix is shown in Table 3. As an example, the form in a design directly depends on the radius but the radius does not play a very significant role in deciding the overall impact of form. At the same time, tension (i.e. the monotony or the lack of it in a surface) directly affects and plays a significant role in deciding the character of a form.

Table 3. Relationship Matrix between Styling Functions and Parameters

	Radius	Straightness	Tension	Lead-in	Crown	Continuity	Acceleration	Sharpness	Space
Form	2	2	3	3	3	0	3	3	3
Color	0	1	1	1	1	1	1	1	1
Unity	2	2	2	3	2	0	2	3	0
Dynamism	2	2	2	2	2	2	0	3	3
Reflections	3	3	2	2	3	3	2	3	0
Ergonomics	1	0	0	0	1	0	0	2	3
Aerodynamics	2	2	3	2	3	0	0	3	3
Manufacturability	3	0	0	0	0	0	0	2	3

Interrelationship matrix: This denotes the interrelationship between different styling function. This interrelationship has two aspects: Interrelationship index (i) and weightage (w) where ‘w ‘is calculated as a function of ‘i ‘. Interrelationship index is again measured on a scale of 0-3 where:

0: No relationship; 1: Weak relationship; 2: Strong relationship 3: Self

Having determined the value ‘i ‘between various functions as shown in table-2, ‘w ‘is calculated for any function as (See Table 4)

$$w= i.x \tag{1}$$

where $x.\sum i=100$

To illustrate an example, $\sum i$ for color is 8. So, x=100/8=12.5. Now this gives us ‘w’ for colour with itself= 12.5*3=37.5, with form= 12.5*1=12.5 and reflection= 12.5*2=25.

Table 4. Interrelationship Matrix between Styling Functions

		Form	Color	Unity	Dynamism	Reflections	Ergonomics	Aerodynamics	Manufacturability
Form	Relationship Index	3	0	0	0	0	0	0	0
	Weightage	100	0	0	0	0	0	0	0
Color	Relationship Index	1	3	1	1	2	0	0	0
	Weightage	12.5	37.5	12.5	12.5	25	0	0	0
Unity	Relationship Index	2	0	3	1	0	0	0	0
	Weightage	33.3	0	50	16.6	0	0	0	0
Dynamism	Relationship Index	2	2	1	3	1	0	0	0
	Weightage	22.2	22.2	11.1	33.3	11	0	0	0
Reflections	Relationship Index	1	1	0	0	3	0	0	0
	Weightage	20	20	0	0	60	0	0	0
Ergonomics	Relationship Index	1	0	0	0	0	3	0	0
	Weightage	25	0	0	0	0	75	0	0
Aerodynamics	Relationship Index	2	0	0	0	0	0	3	0
	Weightage	40	0	0	0	0	0	60	0
Manufacturability	Relationship Index	2	0	0	0	0	0	0	3
	Weightage	40	0	0	0	0	0	0	60

Quality Rating: All styling parameters have different quality ratings for process elements like detection (D), quantification (Q), correction (C) and verification (V). Quality ratings indicate the power and convenience available to the designer through the process to improve the impact of the styling parameter at a given stage of design. This depends on the facilities and commands inherent in the process and the potential of visceral interaction between the designer and the design. This has been measured on a scale of 0-3 (See Table 5).

Table 5. Quality Rating Scales

Rating	Criterion for Elements			
	Detection	Quantification	Correction	Verification
0	No	No	No	No
1	Just indication	Rough	Rough	Indicative
2	cro-detection or	Good	With rough quantification	Quantitative
3	Both	Micro level	With micro-quantification	Quantitative with feel

After assigning the quality ratings (q) of process elements for various styling parameters at different stages of various routes as defined in figure-1, we define another term Cumulative Quality Rating (CQR), which we will denote by q_c, which is calculated as $q_c = \sum q/4$ for the first step and for subsequent steps $q_c = \sum\sum q/4$, i.e. adding the quantity $\sum q/4$ to the q_c calculated for the preceding step. To illustrate an example (See Table 6), Quality ratings for styling parameter 'Radius' calculated for first stage of route-1 are 0,0,0 and 0 for process elements D,Q,C and R respectively and so the CQR for the step is $\sum q/4=0$. Now 'q' for next step are 2, 0, 1 and 1 and CQR for this step = $\sum q/4+0=4/4+0=1$. For the next step CQR= (2+3+3+2)/4+1=3.5 and for the last step CQR= (3+3+3+3)/4+3.5=6.5. We can observe that CQR indicates the quality of design as it matures through different stages.

Table 6. CQR Calculation for the Three Routes

			Radius				Straightness				Tension				Lead-in				Crown				Continuity				Acceleration				Sharpness				Space			
			D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V
	2D Sketch	Capacity	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	1	1
		CQR				0				0				0.75				0.75				0				0				0.75				0.75				0.75
Route-1	Hard Clay Model	Capacity	2	0	1	1	1	0	1	1	2	0	1	1	2	0	1	1	2	0	1	1	1	0	1	1	2	0	1	1	2	0	1	1	2	0	1	1
		CQR				1				0.75				1.75				1.75				1				0.75				1.75				1.75				1.75
	Scanned Data	Capacity	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
		CQR				3.5				3.25				4.25				4.25				3.5				3.25				4.25				4.25				4.25
	Master Model	Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	0	0	3	3	3	3	3	3	3	3	3	3	3	3
		CQR				6.5				6.25				7.25				7.25				6.5				6.5				7.25				7.25				7.25
			Radius				Straightness				Tension				Lead-in				Crown				Continuity				Acceleration				Sharpness				Space			
			D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V
	2D Sketch	Capacity	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	1	1
		CQR				0				0				0.75				0.75				0				0				0.75				0.75				0.75
Route-2	Virtual Clay Model	Capacity	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
		CQR	2,5							2.5				3.25				3.25				2.5				2.5				3.25				3.25				3.25
	Clay Model	Capacity	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2
		CQR				4.25				4.25				5				5				4.25				4.25				5				5				5
	Virtual Clay Model	Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		CQR				7.25				7.25				8				8				7.25				7.25				8				8				8
	Master Model	Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		CQR				10.25				10.25				11				11				10.25				10.25				11				11				11
			Radius				Straightness				Tension				Lead-in				Crown				Continuity				Acceleration				Sharpness				Space			
			D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V	D	Q	C	V
	3D Sketch	Capacity	1	2	2	2	0	0	0	0	1	2	2	2	1	2	2	2	1	2	2	2	0	0	0	0	0	0	0	0	1	2	2	2	2	2	2	2
		CQR				1.75				0				1.75				1.75				1.75				0				0				1.75				1.75
Route-3	Virtual Model	Capacity	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
		CQR				3.75				2				3.75				3.75				3.75				2				2				3.75				3.75
	Virtual Reality-1	Capacity	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
		CQR				5.75				4				5.75				5.75				5.75				4				4				5.75				5.75
	Master Model	Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		CQR				8.75				7				8.75				8.75				8.75				7				7				8.75				8.75

Having calculated the CQR for each styling parameter at every stage of various routes, we define two more terms for each styling function- Total Quality Level (TQL) and Weighted Quality Level (WQL). We define TQL as:

$t_f = \sum q_c . r_f$ Where t_f =TQL for function f at a stage of a styling route; q_c =CQR for styling parameters at the stage from table-3: r_f = Relationship index for the function f with the parameters. To illustrate an example, we calculate TQL for the function 'form' for 2D sketch stage in route-1 in Table 7.

Table 7. TQL Calculation for Function 'Form'

	Radius	Straightness	Tension	Lead-in	Crown	Continuity	Acceleration	Sharpness	Space
r_{form}	2	2	3	3	3	0	3	3	3
qc	0	0	0.75	0.75	0	0	0.75	0.75	0.75
q_c*r_{form}	0	0	2.25	2.25	0	0	2.25	2.25	2.25
t_{form}	11.25								

Weighted Quality Level can be defined as:

$$WQL_f = \sum t_g * w_{fg} \tag{2}$$

where WQL_f = WQL for function f

t_g = TQL for function g

w_{fg} = Weightage for interrelationship of function f with function g from Table 2.

An example has been illustrated in Table 8 for calculating WQL for ‘form’ for first stage of route-1.

Table 8. WQL Calculation for Function ‘Form’

	Form	Color	Unity	Dynamism	Reflections	Ergonomics	Aerodynamics	Manufacturability
t_g	11.25	3.75	7.5	7.5	6.75	3.75	8.25	3.75
w_{fg}	1	0	0	0	0	0	0	0
$t_g * w_{fg}$	11.25	0	0	0	0	0	0	0
$WQL_f = \sum t_g * w_{fg}$	11.25							

Similarly WQL for all functions for all stage of the three possible routes is calculated.

5 RESULTS AND DISCUSSIONS

Plotting the WQL values for all functions for the three stages (Figure 4), we get the quality level of design that can be achieved at different stages of the routes. More important than the ultimate quality level achieved is the question that how early we achieve a better quality level. This is important because this gives the opportunity to the designer to introduce changes early and even change course if needed. The later this realization comes, the more difficult it becomes.

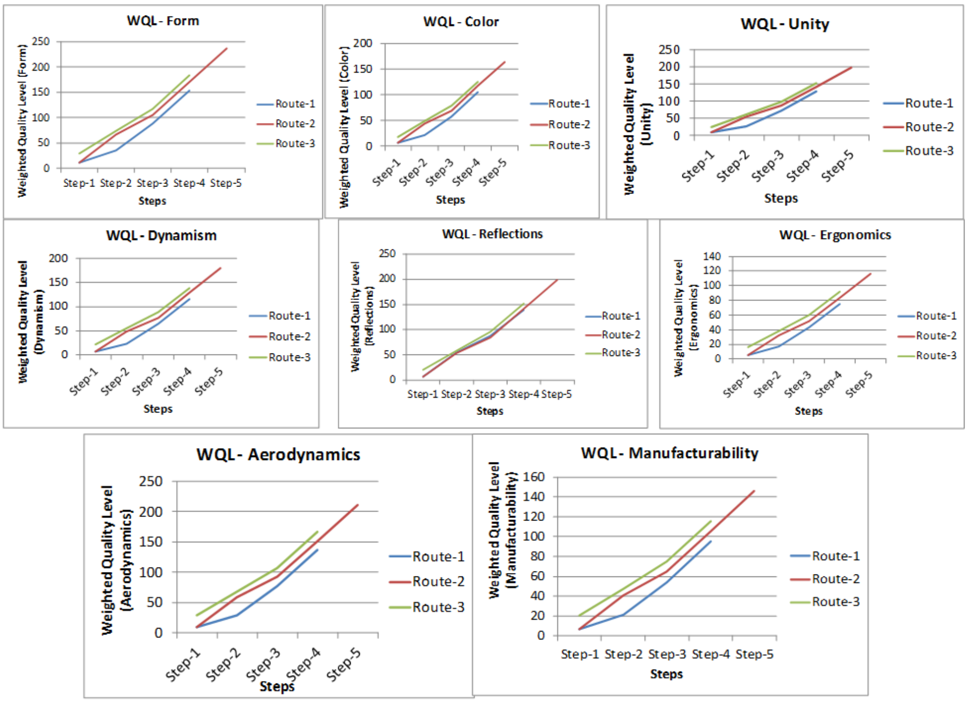


Figure 4. Result Trends for Styling Functions: Cumulative WQLs for Various Routes

These results show a mixed trend. Overall value addition (WQL) in each step is best in completely digital route i.e. route-3(represented by the green line) for all styling functions. But a closer examination tells that, this is solely due to the head-start it gets in the first step, where 3D sketching provides the best advantage in terms of detection and quantification. In subsequent stages, the second route (represented by the red line) adds best values due to the mix of digital quality of quantification and correction and the touch and feel quality of clay model. This observation offers a new direction where the first step in the second route can be replaced by 3D sketching to give best value addition possible (See Figure 5). Therefore we explore route-4.

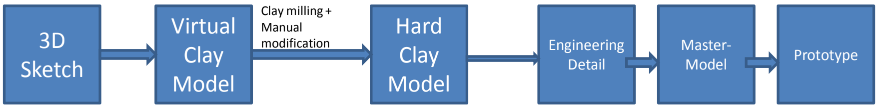


Figure 5. New Alternative Route (Route-4)

Repeating the value addition analysis of route-4 and comparing with other routes, we get the resultant trends as given in following figure (See Table 9 and Figure 6).

Table 9. CQR Calculation for Route -4

3D	Capacity	1	2	2	2	0	0	0	0	1	2	2	2
Sketch	CQR				1.75				0				1.75
Virtual	Capacity	2	3	3	2	2	3	3	2	2	3	3	2
Clay	CQR				4.25				2.5				4.25
Clay	Capacity	2	2	1	2	2	2	1	2	2	2	1	2
Model	CQR				6				4.25				6
Virtual	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Clay	CQR				9				7.25				9
Master	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Model	CQR				12				10.25				12

3D	Capacity	1	2	2	2	1	2	2	2	0	0	0	0
Sketch	CQR				1.75				1.75				0
Virtual	Capacity	2	3	3	2	2	3	3	2	2	3	3	2
Clay	CQR				4.25				4.25				2.5
Clay	Capacity	2	2	1	2	2	2	1	2	2	2	1	2
Model	CQR				6				6				4.25
Virtual	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Clay	CQR				9				10.25				7.25
Master	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Model	CQR				12				13.25				10.25

3D	Capacity	0	0	0	0	1	2	2	2	2	2	2	2
Sketch	CQR				0				1.75				1.75
Virtual	Capacity	2	3	3	2	2	3	3	2	2	3	3	2
Clay	CQR				2.5				4.25				4.25
Clay	Capacity	2	2	1	2	2	2	1	2	2	2	1	2
Model	CQR				4.25				6				6
Virtual	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Clay	CQR				7.25				9				9
Master	Capacity	3	3	3	3	3	3	3	3	3	3	3	3
Model	CQR				10.25				12				12

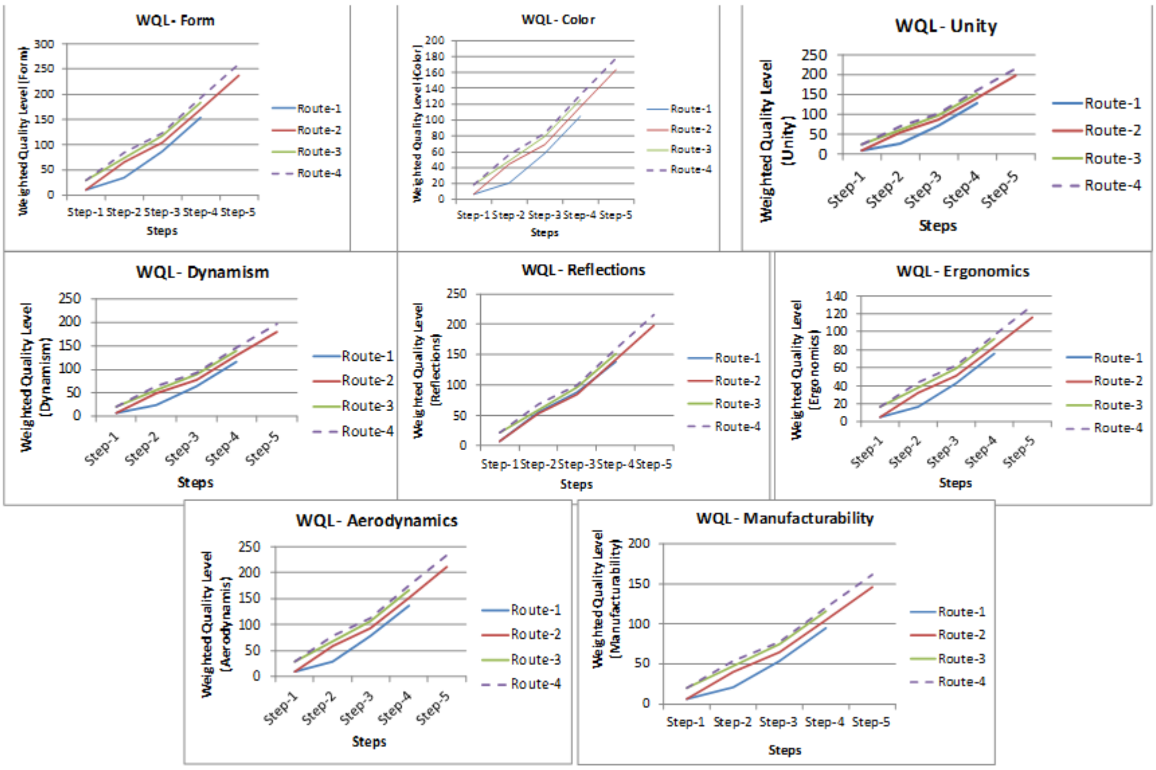


Figure 6. Result Trends for Styling Functions after Including Route-4: Cumulative WQLs for the Four Routes

The resultant trend confirms our hypothesis that the fourth route (purple dotted line) has the highest WQL values at each step. Not only, it gets the best starting WQL value (due to digital sketching) i.e. same as route-3, but adds best values at each step (the advantage offered by route-2) and therefore offers the best value addition in terms of digital advantages and touch-and-feel tangibility.

6 CONCLUSION

Technology is always in a state of transition and new technologies always offer better value additions. This is true in case of clay modeling as well. But before taking a leap, a dispassionate evaluation of all possibilities is needed to get the best mix of new and traditional. At the same time there is an urgent need to get rid of shibboleths of past generated out of sentimental inertia e.g. sketching on paper and clay modeling with hand. So far as the hand-mind-eye co-ordination is concerned the digital age has completely replicated it through digital sketch-pads and pens but complements it with the advantages of quantification. Similarly hand modeling can never achieve the accuracy of digital clay milling based on surface data. So, as history has taught us, if we do not discard the sentimental inertia, the next generation discards it.

This study has attempted to objectively explore the best mix of digital and tangible processes to optimally exploit the advantages of all processes. Though this study has been conducted in context of automobile design, the observations and conclusion can be applicable to any other context as the accuracy and manoeuvrability of digital design and the touch feel quality of manual process should be used in all contexts.

At the same time, the eternal fact remains that all processes, at the best of their capability are as good as the designer. The digital process can only complement his creative input and cannot replace it.

REFERENCES

Aoyama, Hideki and Nishizawa, Yuichiro. (2006) Construction of High Quality CAD Model from Rough Physical Model. Proceedings of 10th International Conference on Flexible Automation and Intelligent Manufacturing (proc. Of FAIM 2000). P. 843-850: 2000/6

Bosinco, Patrick; Durand, Gerard; Goussard, Jaques; Lieutier, Andre and Massabo, Alain. (1998) Complex Shape Modifications. Proceedings of IDMME-Compiegne, France. 1-10

Fontana, M; Giannini, F; Meirana, M. (1999) A Free Form Feature Taxonomy. Eurographics '99. Volume 18, Number 3. 1-13

Fujiki, Hiroyuki and Aoyama, Hideki. (2000) Rapid Construction of Digital Model By Using Virtual Clay Modeling System. 2000. 1-8. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.40.8899&rep=rep1&type=pdf

Giannini, Franca; Monti, Marina; Gerd, Podehl. (2004) Styling Properties and Features in Computer Aided Industrial Design. 321-330. Available at http://www.europeana.eu/portal/record/2023823/V1Nos1to4_37_pdf.html

Hannah, Gail Greet. (2002) Elements of Design, Rowena Reed Kostfellow Foundation. Princeton architectural Press, USA, 9-118

Hummels, C.C.M and Overbeeke, C.J. (1998) Designing and Testing Human Computer Interaction: A Case Study in Virtual Clay Modeling. Coference Proceedings of the 31st International Symposium on Auto motive Technology and Automation (ISATA) pp 27-34

Kai, Hiroshige and Aoyama, Hideki. (2010) Study on Virtual Clay Modeling System Using Refined Curves in Technological Aspects. Proceedings of IDMME-Virtual Concept.pp1-6

Krippendorff, Klaus. (2006) The semantic turn, a new foundation for design. Taylor and Francis, New York.pp 39-175

McCormack, Jay P; Cagan, Jonathan and Vogel, Craig M. (2004) Speaking the Buick Language: Capturing, Understanding and Exploring Brand Identity with Shape Grammars. Design Studies, ElSevier, Volume 25, No 1, January. pp 1-29

Tapke, Jennifer., Muller, Allyson., Johnson, Greg and Sieck, Josh (1997) Steps in Understanding the House of Quality. Available at https://www.thecorporaterookie.com/wp-content/uploads/2014/06/HOQ.pdf