Hybrid Design Tools for Conceptual Design and Design Engineering Processes

Bridging the Design Gap:

Towards an Intuitive Design Tool

Robert E. Wendrich

rawshaping
technology

**HYBRID DESIGN TOOLS
FOR CONCEPTUAL DESIGN AND
DESIGN ENGINEERING PROCESSES**

BRIDGING THE DESIGN GAP:
TOWARDS AN INTUITIVE DESIGN TOOL

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Towards an Intuitive Design Tool

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To Slops

To

PREFACE

It all started many years ago on a beach somewhere down in Southern Europe. You could find me situated right on the fluctuating and irregular coastal seam between the fluid and the solid. Breathing in the salty moist air, enjoying the heat of the sun on my naked body, while sucking in the rays of inspiration. I felt as a part of the world, being in my own imaginative world. Rawshaping is in my blood and what I desire to do unequivocal. Technology and engineering is what I love, especially the orchestration, creation, composing, invention and tinkering of possible solutions through structure, ideation and iterative design processes.

However, I would not be.

I would not be, if not for all before me.

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Science and research demand collaboration and much dedication. Not a thing can be achieved, by one lonely gifted scientist; or singular genius academic honcho; or a sole brilliant soul somewhere hidden in a laboratory, dark basement, stuffy attic or mildewed garage. There are just none such people or things existing. Things are not driven only by/or through 'design', they are mostly driven by serendipitous luck and hard work. This thesis is the result of much collaboration, cooperation and concerted effort of many dedicated 'young' people alongside the author.

We are merely common, down-to-earth mortals, joined in cahoots, be it loosely fitted, colluding or conspiring together secretly on a shared topic called rawshaping technology, but always 'in the raw'.

My acknowledgements and many thanks go to those who felt the spirit, drive, urge, rawness, need, strive, heart, beat, and dedication to follow suit. Over the years the organic, holistic organization of rawshaping, underwent many changes, distortions, upheavals, reformations and misrepresentations. In the end some core characters maintained, committed, persistent and contributed unconditionally within the group and they consistently showed their passion, tenacity and devotion in the raw unambiguously.

First of all my gratitude and a big thank you goes to my promotor prof. dr. ir. Fred J.A.M. van Houten who supported, guided and contributed to my RST research from the beginning. Fred was instrumental in clearing the procedural (often bureaucratic) academic obstacles that come with the promotion territory. His insights and wisdom, loose empathic management style and openness to wild and raw ideas reassured me to go on with the quest full-blown. One of his noted remarks directed me: "Keep writing!" So, I did! Over the years we collaborated on many projects together (e.g. VR-Lab, driving-simulator, SPARK, RST), he always managed to find "money" to support raw-music events that I organized and put together for IDE (e.g. Lee Ranaldo & Psychedelic Films from the Sixties; MOSS & Fritz Lang's 'Metropolis'), funded road-trips with my team to scientific events and travel to the many conferences I attended all over the world. Naturally,

we also had our battles, fall-outs and discussions, but always in good faith, humor and focus on our joined interests. Fred you truly are a praw-motor.

In the early years I drank a lot of coffee and had many discussions and conversations about academic life, technology and research with my colleagues Hans Tragter, Frans Kokkeler and Sipke Hoekstra in their office just across the hallway from my raw-cubicle. It played a subtle role in getting my head around what I wanted to do with my research. Thanks guys! In August 2009 I got an email from Hans in which he clearly explained the quintessence of doing research, to write articles, to get published, to write a thesis and how easily you could get promoted after doing all this, subsequently getting a raise afterwards. I always liked the idea of promoting myself. Thanks Hans (et al.) it happened, although it took time and perseverance, it was all worth it.

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Pivotal and crucial to the success of Rawshaping Technology (RST) research and development project I dedicate a personal thank you 'for taking the raw ride with me' (disorderly listed) as follows:

Olaf 'Tinkerboy' Grevenstuk and Werner Helmich, you gents are unbeatable, devoted, highbrow and truly awesome. Olaf your Pizza Gigante is unforgettable. W! damn them Beatles can sing, we too...Pizzazz Galore! Daniël Poolen, danki asina hopi! Bo ta gran í un alegria na traha ku, mi amigu. Luncheon@deBalie. Herman Weeda always there, inspired, thoughtful, jammed, analytic, visionary and musically fused! Awesome! Sefrijn Langen the independent, tinkerer, artist, holistic and spiritual rawshaper. Gijsbert Dossantos for his calm talent, dread-locks, coding skills and endless efforts to connect raw-kinect.

Renske Herder for her work, wit and analysis on shape-form of iconic design artefacts. Casper Tromp

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Jan Kleine Deters coupling the brain and computer with a tangible frown interface for untethered interaction with the LFDS. Raise the raw flag in praise! Peter Schaefer a creative rawshaper and tinkerer who prototyped tangible pods to synthesize shapes and sound to create scapes and visual simulations. Roh Mittelpunkt der Welt!

There are so many contributors and supporters (raw zealots) that it is extremely hard to distinguish between them. Most likely there will be omissions

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SUMMARY

Hybrid Design Tools; Representation; Computational Synthesis.

Non-linear, non-explicit, non-standard thinking and ambiguity in design tools has a great impact on enhancement of creativity during ideation and conceptualization. Tacit-tangible representation based on a mere idiosyncratic and individual approach combined with computational assistance allows the user to experiment, explore and manifest their ideas, fuzzy notions and mental images. One of the most difficult tasks of individual users is the externalization of tacit knowing, tacit expectations, and metacognitive feelings. Simply put, to bring your imagination alive you need encouragement, nudging, decision-making and trigger intuition. In our research we focus on the metacognitive aspects of user interaction, user experience, user engagement and tool use wherein the wheels of causality are set off through coincidence, unpredictability and unexpected events. The hybrid design tools we author and build are based on the human intuitive capacity and sensory abilities to immerse in physical manipulation and tangible representation to enhance creativity and ideation process. Simultaneously we embed and implement computational design tools that assist and nudge the user during the process to represent the conceptual models, data mapping and transformative information. This transformation has a consequence of exercising the full cognitive abilities and reinforces the insight in understanding and knowledge about the problem definition and solution space. Working visually and sensory is a complex process that includes spatial information, multi perception and manual dexterity.

SAMENVATTING

Hybride Ontwerpgereedschappen; Representatie; Computers en Synthese.

Ontwerpgereedschappen, methoden en processen die gebaseerd zijn op niet-lineaire, niet vooraf bepaalde gedachten en/of gelijkvormig denken, kunnen een grote invloed hebben op het verhogen van de creatieve vermogens en uitingen tijdens de ideesprong, de beeldvorming en het ontwerpen.

Door de individuele en eigenzinnige benadering van impliciete kennis en het uitdrukken van metacognitieve vaardigheden te combineren met behulp en integratie van computers en digitale technologieën, wordt de gebruiker in staat gesteld om vrijuit te experimenteren, te exploreren en zijn/haar ideeën, vage gedachten en denkbeelden manifest te maken. Eén van de moeilijkste opgaven voor individuele gebruiker(-s) zijn de externalisatie en het uiten van onbewuste- (impliciete), onverwachte- en metacognitieve kennis en gevoelens. Om je intuïtie en verbeelding tot leven te brengen, is het van belang dat je als gebruiker wordt gestimuleerd, aangemoedigd en gemotiveerd om tot daadkracht en visualisatie van ideeën en gedachten te komen. Simultaan daaraan, teneinde intuïtie teweeg te brengen, zou met behulp van een computer systeem de gebruiker een 'duwtje' worden gegeven om zijn/haar verbeelding de vrije loop te laten, hun 'ideewereld' te ontsluiten en tot het nemen van beslissingen te komen.

In dit onderzoek zijn we vooral gericht op de metacognitieve aspecten van gebruikersinteractie, gebruikerservaringen en betrokkenheid in het gebruik van fysieke- en computergereedschappen waarbij de effecten van oorzaak en gevolg worden afgezet tegenover (reflexief) het toeval (serendipiteit), onvoorspelbare gebeurtenissen en onverwachte manifestaties. De hybride ontwerpgereedschappen, zowel apparatuur en programmatuur die we hebben gemaakt en geschreven, zijn hoofdzakelijk gebaseerd op de intuïtieve vermogens en zintuiglijke capaciteiten van de mens. Hierdoor is de mens (gebruiker) in staat zich mentaal 'onder te dompelen' en zich fysiek te uiten door middel van manipulatie, handelingen en weergave van tactiele indrukken en deze vervolgens om te zetten in een overmaat en overvloed van beeld, beschrijvingen, weergaven en voorstellingen. Door het integreren en inzetten van computer systemen en -gereedschappen gedurende dit proces wordt de gebruiker gesteund, geassisteerd en aangemoedigd (d.w.z. 'duwtje-in-de-rug', 'zachtjes gepord worden') om tot visualisatie, externalisatie en manifestatie van ideeën, conceptuele voorstellingen en ontwerpen te komen (overvloedige ideatie). Al deze transformerende en veranderde informatie, doorlopen procesgangen en gegenereerde data stromen worden opgeslagen, in kaart gebracht in tekst, tijd en beeld om zodoende tot een volledig overzicht van het iteratieve en generatieve ontwerp- en ideevormingsproces te komen. 'Trackback,' oftewel het omgekeerd teruglopen van alle stappen in het doorlopen proces, is hierdoor eenvoudig, snel, doeltreffend en vergemakkelijkt. Deze transformaties hebben als bijkomend aspect en gevolg dat de volledige menselijke cognitieve eigenschappen, talenten en vaardigheden worden aangesproken en dientengevolge versterkt worden door de verkregen inzichten en kennis over de diversiteit en ruimte in oplossingen binnen een gegeven probleemstelling.

De verrichting van handelingen, handigheid, behendigheid en vaardige werkwijzen gekoppeld aan visuele perceptie en zintuiglijke waarneming is een zeer complex proces waarbij gelijktijdig ruimtelijk inzicht en informatie zich vermengen met de talrijke zintuiglijke waarnemingen en gewaarwordingen. De belichaming en inlijving van deze metacognitieve processen staan garant voor een rijkere ervaring en intensere beleving van het opdoen, het verwerken en de applicatie van kennis zowel impliciet als expliciet.

SAMENVATTING (GOOGLE TRANSLATE: 1-ON-1)

Hybrid Design Tools; Vertegenwoordiging; Computational Synthesis.

Niet-lineaire, niet-expliciete, niet-standaard denken en dubbelzinnigheid in design tools heeft een grote impact op de verbetering van de creativiteit in gedachten en beeldvorming. Stilzwijgende-tastbare voorstelling gebaseerd op een louter eigenzinnige en individuele aanpak, gecombineerd met computationele hulp kan de gebruiker om te experimenteren, te verkennen en te manifesteren hun ideeën, fuzzy begrippen en mentale beelden. Een van de moeilijkste taken van individuele gebruikers is de externalisering van stilzwijgende weten, stilzwijgende verwachtingen en metacognitieve gevoelens. Simpel gezegd, je fantasie levend u aanmoediging, nudging, besluitvorming en trekker intuïtie moeten brengen. In ons onderzoek richten we ons op de metacognitieve aspecten van interactie met de gebruiker en het gereedschap gebruik, waarbij de wielen van de causaliteit worden verrekend door middel van toeval, onvoorspelbaarheid en onverwachte gebeurtenissen. Het hybride ontwerp tools die we schrijven en te bouwen op basis van het menselijk intuïtieve capaciteit en zintuiglijke capaciteiten om onder te dompelen in fysieke manipulatie en tastbare vertegenwoordiging van creativiteit en ideeënvorming proces te versterken. Tegelijkertijd we verankeren en implementeren van computational design tools die helpen en nudge de gebruiker tijdens het proces om de conceptuele modellen, data mapping en transformatieve informatie weer te geven. Deze transformatie is een gevolg van de uitoefening van de volledige cognitieve vaardigheden en versterkt het inzicht in het begrip en kennis over de probleemstelling en de oplossing ruimte. Werken visueel en sensorisch is een complex proces dat ruimtelijke informatie, multi perceptie en handvaardigheid omvat.

LIST OF ABBREVIATIONS

AE = Emotional Awareness	LFDS = Loosely Fitted Design Synthesizer
AFIF = Airflow Interface	LFIS = Loosely Fitted Image Synthesizer
AM = Additive Manufacturing	LM = Logic Mode
API = Application Programming Interface	MIDI = Musical Instrument Digital Interface
AR = Augmented Reality	MR = Mixed Reality
BCI = Brain Computer Interfaces	OR = Oculus Rift (VR goggles)
CAD = Computer Aided Design	PCP = Product Creation Process
CAX = Computer Aided Technologies	PEP = Product Engineering Process
CCDS = Collaborative Cloud Design Space	PSS = Product Service System (-s)
CGS = CAD Game System	QDA = Quantitative Data Analysis
COTS = Commercial-Off-the-Shelf	RBI = Reality-Based Interaction
CPS = Cyber-Physical System (-s)	RSFF = Rawshaping Formfinding
CPU = Central Processing Unit	RST = Rawshaping Technology
CSDS = Cross Sectional Design Synthesizer	SFS = Shape-from-Silhouette
CVE = Custom Value Engineering	SI = Primary Somatosensory
DDT = Digital Design Tool (-s)	SOTA = State-of-the-Art
DOF = Degrees of Freedom	SVRE = Social Virtual Reality Environment
ED = Engineering Design	TCP = Transmission Control Protocol
EEG = Electroencephalogram	TP = Tangible Pods
FM = Fuzzy Mode	TUI = Tangible User Interface
FOV = Field of View	UE = User Engagement
GE = Geometry Engine	UP = User Performance
GPU = Graphics Processing Unit	UX = User Experience
GUI = Graphical User Interface	VDA = Virtual Design Assistant
HCI = Human Computer Interaction	VE = Value Engineering
HDT = Hybrid Design Tool (-s)	VFG = Virtual Formgiving
HDTE = Hybrid Design Tool Environment (-s)	VIA = Video Interaction Analysis
HMD = Head Mounted Display	VR = Virtual Reality
HMI = Human Machine Interaction	WIMP = Windows, Icons, Menus, Pointer
IA = Interaction	
IDE = Industrial Design Engineering	in the raw = ¹ in its true state; not made to seem better or more palatable than it actually is: <i>he didn't much care for nature in the raw.</i>
IF = Interface	² informal (of a person) naked: <i>I slept in the raw.</i>
IxD = Robust Interaction Design	
KPI = Key Performance Indicators	

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3-D voxel shape by Marcel Goethals

On Reading This Thesis:

What lies in this thesis is perhaps more important as a whole than its constituent parts. If you only have a little time, perhaps only an hour or so, to spend on reading this work, it makes more sense to read the whole thesis rawly in that specific period of time, than to read only the first three chapters in detail. For this reason, the whole thesis can be read chapter by chapter since I have arranged it so that each chapter could stand and inform by itself. However, if you decided to read the whole thesis at once, within your previsioned time frame, just scan and speed read without trying to grasp the detail but feeling the scope and breadth of the rawshaping paradigm. In return the thesis will unfold, transpire and explain itself without any more ado or effort elicited from the reader. The detail will superfluously become clear within the probability, structure, viewpoints and wider context of the "raw whole" emerge as a holistic interplay of phenomena.

The thesis is based on a concise selection of approximately forty (40) peer-reviewed key articles, book chapters and papers, written in the period from November 2008 until May 2016. The chapters are structured chronologically and present the evolution of ideas, views, tools, knowledge and change of perspective during our ongoing research and development over the period of study and reflection.

In this thesis, the words "she", "her", and "her" may also be read as "he", "him", "it" and "his", respectively.

CHAPTER 1

Introduction The Rawshaping Paradigm

The research presented in this thesis concerns the development of a new product design and design engineering attitude, rather than a novel method per se, in conjunction with hybrid design tools (HDT). HDT's are cyber-physical systems (CPS) based on analogue and digital technologies that create a semi-immersed interaction state, often referred to as a mixed- or augmented reality.

This chapter introduces the background of the research, whereby imagination and reasoning are instrumental to grasp the rawshaping philosophy as a creative source of discovery. Furthermore, the objective, approach, attitude, rawshaping framework and an outline of the thesis are discussed.

1.1 Tools and Methods in Early-Phase Design Processing

The long-term objective of this research is to develop computational design tools and systems that support and assist users in their design activities (Fig. 1). Product design and engineering are a complex set of activities beset not only by limiting enablers but additionally by the unwitting impact of mediocre designs (Cross, 1984 and Kosmadoudi et al., 2013). Small errors in the early design phases may not become apparent until much later in the process or until it becomes too late. Ideation is the “ability one has to conceive, or recognize through the act of insight, useful ideas” (Vaghefi et al., 1998). Nowadays computational tools are the standard in design and engineering and play a crucial role in the design process. There are many views on the massive change that Computer Aided Design (CAD) caused (Robertson et al., 2009), how it influenced user behaviour, user intent, user-experience, user-interaction, and user-performance and productivity (Wendrich, 2013c, 2013d). Current CAD systems (enabler) are governed by rigid rules and predetermined “canonical” procedures that limit user/designer creativity and intuition¹ (Kosmadoudi et al., 2013). The transition from masses to user-centred design paradigms sees design and engineering activity and creativity being compromised. The complexity of products has increased dramatically with mechatronics and adaptronics. In a globalised world, interdisciplinary and trans-disciplinary product development are part of everyday life. Further complexity is introduced with the demand of Product Service Systems (PSS) (Birkhofer, 2011). In product development, there is an increasing division of labor. The reduction of production depth is accompanied by a comparable reduction in “design-depth”. As a consequence the deep meaning of personhood is being reduced by illusions of bits; people degrade themselves in order to make machines seem smart all the time (Lanier, 2010). Designers become project managers with product responsibility from the product idea all the way to the release for series production (Birkhofer, 2011). If responsibility for product ideas is part of the designers’ task description then this aspect should be a fundamental part of the designer’s skill set and education. Key aspects of the design and engineering process, e.g. analogue ideation, intuition, manual skills (i.e. paper modelling, low-resolution modelling), tacit knowledge, and creativity became somewhat trapped and challenged with CAD. Current CAD developments make slow progress towards enactive modes of operation, but still far off from what humans can accomplish in terms of cognitive transformations, sensorimotor representations, through visual manipulations to fully matured formal operations (Sener, 2002). The notion of creating playful CAD environments as a transformation technology to address current drawbacks such as complex menus, limited interactive assistance during the design tasks, formal conceptual design tools and fixation on design routines that stifle users’ creativity, ideation and intuitive process are therefore highly important. The development of methods and tools to support the design process started in the early 1960s with interactive systems mimicking the drafting and calculation tools. This is the area of interactive design where the process of developing solutions to a given set of requirements and constraints cannot be reduced to an algorithmic or procedural process. The sequential steps imply evaluations and decisions that are taken by designers on the basis of global assessments (Bordegoni et al., 2009). Mixed prototyping, which is the practice based on the use of prototypes consisting of a mix of real and virtual components, has proved more effective for the assessment of interactive products with respect to totally real or totally virtual prototypes (Bordegoni et al., 2009). The development of hybrid tools (mixed reality) and rawshaping procedure (holistic method) to support design processing

¹ ‘Intuition is a process of thinking. The input to this process is mostly provided by knowledge stored in long-term memory that has been primarily acquired via associative learning. The input is processed automatically and without conscious awareness. The output of the process is a feeling that can serve as a basis for judgments and decisions.’ - Tilmann Betsch & Andreas Glöckner (2010)

started in 2004 (Wendrich, 2012a, 2012b) with the integration and implementation of interactive systems in mixed reality (See http://rawshaping.com/documents/FG_TBK-Report2004.pdf).

Figure 1. Hybrid design tools development and experimentation

1.2 Hybrid Design Tool Environments (HDTE)

The computer was made in the image of the human (Simon et al., 1983). Technological constraints are a given challenge and working within them always fosters creativity. Ideation (i.e. design and creativity) is still done with traditional analogue manual tools and are used next or parallel to current computational tools. Our tools dictate the nature of our work². Often software interfaces define the boundaries of our work, but only exploration into the margins of these tools, beyond the intended use pattern can really expose these boundaries. In that sense in order for us to break out of the design paradigm embedded in software we must use it “the wrong way” (Fail Gracefully, 2009). The research on hybrid design tool environments (HDTE) for design and creativity, tries to provide a simple, effective, flexible and efficient workflow and still not limit the creative output and ideation processing. In combination with game-based CPS ecosystems (e.g. hybrid design spaces, CAD-games) the creative human capabilities (inspiration and imagination) and capacity to playfully collaborate or work alone in design and engineering processes coincide with the intuitive natural human ability to interact, communicate and challenge conventional thinking (Kosmadoudi et al., 2013). Tools support and assist designers and engineers in their daily interactions with real and virtual worlds, in conjunction with the meta-cognitive aspects and intentionality of the user (-s). Most of our tools enable us to acquire a natural or synthetic extension of the physical and/or virtual realms and enhance the human capability and capacity in their interactions with these multiple realities.

In the past forty years, what we have learned and embodied in our techno-design, e.g. (Heisenberg, 1998), (Duchamp, 1934), (von Foerster, 1973), (Varela et al., 1974), (Latour, 1988), (Baudrillard, 1994),

² 'It is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.' Tools not only provide the power to shape materials, but frame the dimensions of human intellect. There is magic in the manipulation of real tools and real materials.' - Abraham Maslow (1908-1970)

is that reality is constructed and we each build ‘worlds’ in our own different ways. We mirror that understanding in our virtual realities, and bring both ambiguity and sophistication to the idea with mixed reality technology (Ascott, 2006). In this blend of consensual realities, the habitual and the virtual are fused. Robust interaction design (IxD) is therefore crucial to support the way designers and engineers (people) interact and exchange information and communicate throughout the design process. Rationalizing and externalizing the thought process that led to the insight is necessary to communicate the knowledge with others and make it plausible for them. Brereton (1999) uses the term ‘distributed cognition’ as “the process of designing and developing design understandings”. Distributed cognition during ideation and interaction with predetermined or loosely defined constraints is essential to manifest ideas, explore fuzzy-notions and stimulate inventiveness (Wendrich, 2009, 2011b). Most computer aided design (CAD) tools do not fully support ideation, externalization and creativity processing, especially not during the early phases of design processing, e.g. (Sener 2002), (Wang et al., 2002), (Bilda & Gero, 2005), (Wendrich, 2012a, 2015a, 2015b), (Liu et al., 2014), (Kosmadoudi et al., 2014). We propose heuristic shape ideation to support creativity, intuition, tacit knowing and reflection-in-action. The thesis concludes by the consideration of possible pathways for expanding the perspective of human-computer interaction (HCI) through the use of robust interaction design (IxD), gamification and affective computing.

1.3 Blended Spaces and Hybrid Design Tools

McCullough (1996) stated: ‘We must look very closely at craft. As a part of developing more engaging technology, as well as developing a more receptive attitude toward opportunities raised by technology, we must understand what matters in traditional notions of practical, ‘form-giving’ work.’³ This will require the study of tools, human-computer interaction and practice of the digital medium.’ Duchamp (1934) denounced the superstition of craft, the artefact is a projection of a three-dimensional object that in turn is the projection of an (unknown) four-dimensional object. The artefact is therefore the copy of a copy of the idea. Ascott (2006) questioned what that real reality might be? The ‘space’ created by various blended realities (mixed realities) is malleable (though fixed in spectral terms), we react to it individually and idiosyncratically. Beyond merely a blended space, we accept our mixed realities as montage-like interpretations of realities and create illusions of realities that differ substantially from ‘original’ experiences. Mixed reality technology provides us thus with another skin, another layer of energy to the body and add to the complexity of its field (Ascott, 2005). Human experience and meaning depend in some way upon the body, for it is our contact with the entire spatio-temporal world that surrounds us. The key questions that must be asked are thus: Are embodied representations, our expressions developed from our bodily perceptions and imaginative systems of understanding, adequately shared to be thought of as appropriate to knowledge? Or, are they too subjective, unstructured and unconstrained? To paraphrase Johnson (1987), “...there is alleged to be no way to demonstrate the universal (shared) character of any representation of imagination.”

According to Schön (1983) it seems right to say that our knowing is in our action and interaction. In the fuzzy front end of creative processes, ideas are often visualized in one’s imagination and externalized through 2-D and/or 3-D representations. Our approach incorporates the human embodiment (human) and interactions in conjunction with blended environments (machine), hence, interactive

³ ‘The ultimate object of design is form. Every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem.’ - Christopher Alexander (1964)

hybrid design tools and environments (HDT-E). The centrality of human embodiment (Fig. 2 right) directly influences what and how things can be meaningful to us, the ways in which these meanings can be developed and articulated, the ways we are able to grasp and reason about ideas, experiences, and the actions we take (Fig. 2 left). Embodied understanding is a key notion, we are never separated from our bodies and forces and energies acting upon us give rise to our understanding (our “being-in-the-world”). So, this “being-in-touch-with reality” is basically all the realism we need.

Figure 2. Hybrid design tool environment (HDT-E) (right) and user engagement (UE) process flow (left)

his realism consists in our perceptions and sensorial understanding that makes us feel, touch, explore, and come-to-grips with reality in our bodily actions in the world. Moreover, we need to have an ample enough understanding of reality to afford us to fulfill a purpose or task successfully in that “real” world. Polanyi (1966) describes the human body as an instrument, the only instrument that we normally never experience as an object. Because we experience our body in terms of the world to which we are attending from our body “...we feel it to be our body, and not a thing outside” (Polanyi, 1966). The HDT(E) holistic approach is based on the dynamic and agile development of HCI, along with the inclusion of meta-cognitive affordances, intuition, and bodily experiences. Miller et al. (2005) state that intuition comes in two types; either holistic hunches, or automated expertise. A holistic hunch is a judgement or choice made through subconscious synthesis of information drawn from previous experience and knowledge. Automated expertise happens when judgements or choices are made through a partial subconscious (i.e. autonomous, self-aware) process involving recognition of the situation. However, often it is the software alone that defines and determines how and what actions are possible within a virtual reality. As a result 3-D modelling tools (CAD) on a computer, are not unlike e.g. ‘hammers’ and impose limitations to the solution space. These limitations have direct implications to the freedom of a designer, as well as the understanding of form and shape of virtual models (Kruiper, 2015). According to Dyck et al. (2003) current CAD systems do not have a strategy to communicate between the system and the engineer to enhance the UX. Games on the other hand “...communicate information to users in ways that do not demand the user’s attention and do not interrupt the flow of work” (Kosmadoudi

et al., 2012). Humans excel at using resources, especially representational resources, in systematic but creative fashion to work their way to solutions. They are good at using and manipulating structures and constructs (Kirsh, 2005). Brereton (2004) describes four dimensions along which representations can be classified. Embodied imagination (physical experiences and its structures), intentionality, and metacognition could simultaneously 'link' this imagination (individually or collaborative) congruous with the digital realm based on our natural physical and intuitive interactions and explorations. Human attention fluctuates between meaning, timbre, texture, rhythm, syntax, pitch, colour, shape and form, creating a complex weave in which the total package matters less than the aggregation of the individual characteristics of perceived objects and /or artefacts. Lastra (2000) stated: There is never a fullness to perception that is somehow 'lost' by focusing on a portion of the event, by using the event for certain purposes, or simply by perceiving with some particular goal, say understanding or insight, in mind. When a thought process is categorized into intuitive and rational processes, the intuitive system (System 1) is characterized by the keywords: fast, immediate/automatic, slow learning, effortless and associative. The rational, conscious system (System 2) is characterized by the keywords: slow, controlled, flexible, effortful, and rule governed (Kahneman, 2011). Flow separates and combines both forms of thinking: concentration on the task and deliberate control of attention (Wendrich, 2013c). The deep meaning of embodied cognition is that it enables disembodied thought (Tversky, 2005). Blending realities was already present during the initial wake of the computer-revolution; the idea of 'disembodied cognition' became very popular, e.g. (Tversky & Hard, 2009), (Mahon & Caramazza, 2008). The trouble here is that being 'disembodied' created great challenges, frustrations and problems to solve in human interaction with machines.

1.4 HMI/HCI Pleasure: Tool Experiences in Mixed Realities

Interaction, Ideation and Design Representation constitute an important proportion of any design and engineering process. Tangibility, tactility in perception and manual dexterity during these phases are highly undervalued in current human machine interface (HMI) and human computer interaction

(HCI) design, systems and applications. Usability of computational tools and systems often (i.e. mostly) lack the inclusion of metacognitive, sensory and/or physio-psychological aspects, whereby the loss of tactile spatial acuity are deteriorating and lead to degradation over time in users. The need for embedding and inclusion of the aforementioned aspects in the design engineering process calls for new perspectives, holistic viewpoints, and novel approaches towards HMI/HCI (Fig. 3).

Computer games, for instance, often help to enhance our motor coordination, visual perception and spatial reasoning (Kosmadoudi et al., 2014), (Garbaya et al., 2014). Play is not characteristically undertaken to acquire some extrinsic benefit. The essential function of play is the modulation of experience. Humans can excel in interactions and

Figure 3. The Embedded Mixed Reality Continuum

communication with others and possess amazing capabilities to use these complex skills to gather information or have an influence on others behaviour (Fig. 4). However, computers and systems are getting better and better in doing virtually the same complex set of sensorial 'understanding' and recognition of recurring motives. Virtual assistants (robots) are quite common practice these days (i.e. services, communication, and information) and are often more cost-effective and efficient in their repetitive task fulfilment and core functionalities. Humans continue to have, at least for the time being, an advantage in the physical domain in which they use their abilities and capabilities often in advanced and complex situations in either physical or cognitive challenges (i.e. communication, psychology, cognition). People are great problem-solvers in physical and metacognitive processes that are, often ambiguous, non-linear, risky, predictable or unpredictable, but always in a state of motion, requiring explicit intention and interaction.

Figure 4. The positive drivers for the Design Engineering Process (Wendrich & Kruiper, 2015)

"...we must look very closely at craft. As a part of developing more engaging technology, as well as developing a more receptive attitude toward opportunities raised by technology, we must understand what matters in traditional notions of practical, form-giving work. This will take some study of tools, some study of human-computer interaction, and some study of practicing the digital medium" (McCullough, 1998).

Once you immerse yourself in the digital virtual realm questions arise; "What about tangibility, manual dexterity, tactility and sensory perception?" (Wendrich, 2009-2016)

1.5 Abstract Representation Through Embodied Imagination

A main task of industrial designers is the shaping and transformation of ideas or fuzzy notions into abstract or tangible abstract equivalents. These representations can be described as the sum of form and shape aspects, aesthetics, tacit knowledge, intuitive qualities as well as technical and sustainable functionalities. The designer must fully understand all the elements involved in this synthesis of representational design processing. To be successful they need to compose⁴, orchestrate, shape and form all characteristics carefully and join them into harmonious and balanced artefacts while simultaneously steering within implicit and explicit mechanical and functional aspects (Wendrich, 2009-2010a).

1.6 Ideation and Conceptualization

The ideation and conceptualization of ideas and fuzzy notions during design- and product creation processes play an important part in the development of products and communications between designers, design engineering teams and organizations. In all levels of interaction and communication between different players, stakeholders and managers the interpretation of ideas or concepts are often not congruent, well understood or easily accepted due to misinterpretation of data, differences in stakes and viewpoints often caused by data loss or communication breakdowns (Wendrich, 2011c-2012a). With the introduction and emergence of fully digital representation tools the former notion brought about complete new experiences and insights in communicating ideas and creative notions. Some of these constraints were due to stall (e.g. software functionality, high processing times to execute visualizations) and latency in software programming or faulty digital equipment. Cumbersome non-intuitive interfaces and peripheral devices cause problems leading to down-time and user frustration. This subsequently also increased the loss in real-world tangibility and diminished the merit of face-to-face communication. The use of poorly tethered designed interfaces to interact with the software often results in poorer intuitive interactions and lesser tacit understanding (Weiser, 1991-1993), (Ishii et al., 1997), (Van Dam, 1997), (Hartson, 1998), (Caroll, 2000), (Beaudoin-Lafon, 2004), (Dix, 2009), (Wendrich, 2009). The approach for the design tools we introduce in this thesis, are interactive hybrid workbench systems, mobile- and web-based applications that supports analogue and digital design interaction and assists in the design communication for single- and multiple players in collaborative settings.

1.7 Product Creation, Design and Design Engineering Processing

Industrial Design Engineering (IDE) and Engineering Design (ED) are technical domains that have their own specific and intrinsic meanings, processes, procedures and methods. However, crossover relations and similarities are also found in approach, structure, behaviour and interaction in for example a product creation (PCP) and product engineering process (PEP). In our research framework we focus on the multi-disciplinary, collaborative, and mixed reality representation activities and user interactions in conjunction with hybrid computational design tools. Furthermore, we recognize and adhere to the idiosyncrasies, tacit knowledge, expertise and intuitive skill-sets of the individual within the singular and/or collective context. We investigate and test these phenomena through exploration

⁴ 'Composing will always be a memory of inspiration; improvising is live inspiration, something happening at the very moment. Do not fear mistakes. There are none.' - Miles Davis (1969)

1.9 Approach

We use a holistic approach to stimulate intuition, creativity, enhance ideation, trigger imagination and deploy empirical studies on design and engineering processing. The fuzzy front end of any creative process, where forethought takes place to trigger ideas in the mind's eye followed by iterative externalization of ideas, fundamentals our research in human computer interaction (HCI), distributed metacognition, user behaviour, and design representation. The study grounds our theories on observation in the human-in-the-loop and human-on-the-loop aspects of individual or collaborative processing and stresses the importance of face-to-face interaction and communication. Prototype creation, development and production of hybrid design tools are presented, discussed and visualized. A number of educational user studies, interaction experiments, and real world use-cases have been executed, which have given indications for how these tools could enhance and augment the creative design process for designers and engineers (See [Appendix A](#)). The outcomes indicate directions in different types of representation, synthesis of concepts, choice-architecture and decision-making support. The quantitative data analysis (QDA) and validation of user generated processing data draws on video recordings, interviews, and user feedback of design interaction and activity (See [Appendix B](#)). We measure performance, task success, interaction time, number of iterations and user satisfaction. The data provides a hypothetical foundation to support discussions on methods in studying creativity, hybrid (i.e. blending of analogue and digital technologies) support in heuristic shape ideation, impact of tools on imagination in design representation, and holistic shared interaction within mixed reality environments (Fig. 2, Fig. 3 and Fig. 6).

Figure 6. Rawshaping Technology's (RST) empirical research and holistic framework approach

1.10 Outline / Organization of the Thesis

Chapter 1 outlines (Fig. 7) the RST paradigm, background, foundation, and overall approach towards the design and development of hybrid design tools (HDT). Chapter 2 entails the groundwork and initial approach based on our empirical research within design education and user experimentation with a variety of analogue and digital interaction test-benches (hybrid approach) to research and observe users (i.e. novice and expert designers and engineers) in their use of tools and systems. Furthermore, our first prototype of a HDT, the Raw-Shaping-Form-Finding machine (RSFF) is introduced. Chapter 3 presents our second HDT prototype, the Loosely Fitted Design Synthesizer (LFDS) and an explanation of the system architecture, system function and interaction modalities are presented. Chapter 4 is the domain application of HDT's and an Industry use-case study based on Value Engineering. Chapter 5 signifies the agile development and continual improvement of the HDT's. We present an educational case-study design engineering process in conjunction with various analogue and digital (hybrid)

tools based on individual and collaborative interaction. In Chapter 6 we compare three different design tools and representation modalities in early-phase design processing within the educational domain. Three student-groups are observed and measured to test user behaviour, user interaction (IA), ease of tool use, tool performance, tool satisfaction, tool expectations and user experience (UX). Analysis and evaluation of the findings and results are presented. Within Chapter 7 we present several updates and upgrades of HDT mixed reality tools and interaction modalities for the externalization and representation during design engineering processing. Furthermore, we present web-based applications of the HDT's for networked collaborative interaction and representation. Chapter 8 continues with a pair-wise comparison of the LFDS embodiments and interaction modalities based on user interaction and representation, with three main methods for data collection employed observations, on-line survey and user results analysis and evaluation. Chapter 9 is forward thinking and current work on HDT's with virtual reality and social networked collaboration in conjunction with Oculus Rift. Chapter 10 relates and connects directly to Chapter 2 in relation to the evolution and advancements in tool development, design and research in robust interaction design (IxD), user experience (UX) and user engagement (UE). This chapter signifies the processes and progressions over an extended period of time whereby knowledge, findings and results have been integrated and adapted to improve, redefine and optimize our earlier starting points, assertions and assumptions. Chapter 11 concludes this thesis with our contributions and indication of projection and recommendations for future work. Furthermore, recommendations and a final contemplation are presented.

Figure 7. Outline of the thesis

RST Research Timeline

ABSTRACT

Rawshaping Technology (RST) research 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 behaviour during use of "analogue" (traditional) 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 the tacit and tangible elements of design processing back into CAD systems.

Keywords: intuition, tacit tangible representation, hybrid design tool, ubiquitous computing

CHAPTER 2

Raw Shaping Form Finding: Tacit Tangible CAD

(This chapter is based on the peer-reviewed journal paper: "Wendrich, R. E. (2010). Raw shaping form finding: Tacit tangible CAD. Computer-Aided Design and Applications, 7(4), 505-531" and "Wendrich, R. E., Tragter, H., Kokkeler, F. G. M., & van Houten, F. J. A. M. (2009). Bridging the design gap: towards an intuitive design tool. In Proceedings of the 26th ICSID World Design Congress and Education Congress.")

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2.1 Current Design Practice

The Designer or Homunculus Intentio (Fig. 8) shows design activity, uses design representations to visualize and express his/her ideas or fuzzy-notions while at the same time sharing these visual or tangibles with others or oneself. There are many different ways to represent ideas or thoughts on design issues, these modes or strategies they choose to convey or make visible are closely related to intuition, tacit knowing, vocation and experiences of how to represent these entities. Distributed cognition during the design process enables the designer to manifest ideas to explore and shape product ideas, simultaneously manoeuvring 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 design assignments in education curriculum, created various haptic and tangible experiments and explored distinctions between analogue and digital representation techniques. Critical issues emerge from analogue and digital tool use, hybrid combinations and ubiquitous computing, 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. Designers scratch, construct, manipulate and alter the earth resources with their tools, ideas and activities thereby manifesting visions of their design thinking, dreaming, tinkering and creating artefacts⁵. All these actions and interventions are structured or triggered by directing will (automatic system), fuzzy approach (reflective system) and guided by conventions simultaneously re-directed and influenced by the worldly surroundings.

Figure 8. *The Designer with Intent*

2.2 Emergence, Skill and Entropy

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 more and more distant themselves from the physical sensorial perceptions and immersed themselves gladly in virtual digital realities. They were lured into visual

⁵ *'The stone unhewn and cold becomes a living mould. The more the marble wastes, the more the statue grows.'*
- Michelangelo Buonarroti (1475-1564)

poly-dimensional stimulation, worshipping digital virtual realities on high-definition screens, in a make-belief world where the virtual reality steady became the new orthodoxy. This phenomenon has led 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 obvious leading to increasing inertia and entropy. It is virtually impossible to be in sync with a computer or have an emotional attachment to it. Most representational technologies deskill, confuse, simplify control, remove the unpredictable, create loss of serendipity and inflict signs of stall and stagnation in processing leading to entropic tendencies. Woolley (2004) 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 to follow the tailored-system approach learning, learning and experiencing program procedures and categories until conquering the program threshold subsequently by adapting and transforming to it. McCullough (1998) 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 twenty years, we continue to have an ambivalent relation with computers and computational processing.

2.3 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, Engineering and Formgiving. Questions were targeted at student designers, this survey revealed that Virtual Form Giving (VFG) 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 bring out or emphasize skill-set

The findings and results nudged us towards more (re)search and experimentation in the domain of Virtual Reality, Design Tools and Ways of Thinking on Design and Design Science. In a period of five (5) years we implemented several visual and physical abstract representation assignments in the educational curriculum to make observations, measure 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 representation. This could be partially

instigated by proximity and abundance of digital technologies within the realm of design education. Emphasis on sensory perception was far greater than the implementation of sensory feeling within the design solution space. Apparently learning in design is enabled through continually challenging abstract representations against material representations. The comparison shows voids that inspired us to further investigate design processing, design representation, raw approaches on design, ways of thinking, creative intelligence and raw tinkering in design articulation. In sensory perception we rely on our visual system, tracking, and parsing, dodging, spotting, guiding, predicting and sometimes seeing things before they happen. Naturally we have blindspots that allow us to create visual illusions and allow for disembodiment. *Blindspots* (Wendrich and D'Cruz, 2011) are unexpected, unseen, unknown, unforeseen and/or ignored areas of knowledge or gaps in understanding and experience in the world around you. They are a combination of low predictability and large impact once they become apparent. 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. Our aim is to enable and address *blindspots* in engineering design education through the provision of an easily adoptable multi-modal workbench, which will nurture students' creativity and enhance their innovation capacity ([Appendix C](#)).

In general, design and design engineering graduates are not conscious of user requirements, experiences or attitudes and of their importance in design and engineering. Design and engineering curricula do not typically encourage or reward risk taking, non-linear approaches and experimentation, all of which are reported to develop creativity and innovation. Design and engineering education generally lacks encouragement of cycles of divergent and convergent thinking, reflection and incubation that are cited as promoting and developing creativity. Within the design and engineering curriculum design has been highlighted as the key area providing opportunity for developing creativity (Petty, 1983; Charyton et al., 2008; Wong and Siu, 2011). The use of open-ended problem scenarios in design teaching is highlighted as important in developing creativity and providing authenticity to the design experience (Rugarcia et al., 2000; Silva et al., 2009; Page and Murty, 1990). Teamwork/groupwork (collaborative) activities are also cited as important in the development of creativity (Silva et al., 2009; Chan et al., 2005; Wong and Siu, 2011) and these have been shown to lead to enhanced academic achievement (Springer et al., 1999). Development of creative and innovative potential has been linked to exposure to, and development of attitude towards, risk taking (Garavan and O'Conneide, 1994; McWilliams and Haukka, 2008). The development of both divergent and convergent thinking at points within the design process have been linked with creative engineering design (Charyton et al., 2008) and it has been noted that divergent thinking is not particularly encouraged within engineering education (Törnkvist, 1990). Murray and Renton (1988) highlight the importance of awareness of user-requirements and attitudes within design teaching. Divergent thinking processes are linked with developing creativity, and yet Törnkvist (1990) indicates that engineering education does not generally encourage divergent thinking. Webster et al. (2006), as cited by Wong et al. (2011), refer to fostering of creativity through the use of both divergent and convergent thinking, with these happening at key stages of the design process. Howard et al. (2010) focus on tool use. They refer to 'generation tools' such as creative analysis tools, creative thinking tools and creative stimuli tools.

2.4 Tangible Materials

In every indigenous land there live people that work with their hands, in every culture there are people using hand-crafting techniques to create artefacts, in every society there are people working on a daily

basis with their hands doing repetitive tasks or relying on their hands to create extraordinary artefacts. We are our hands, without our hands we have a very 'mute' and sensory feeling deprived world and that could hinder our worldly perception dramatically. The theoretic and practical autonomy of the 'sense of locality' within the sense of touch and its connection to sensory activities of the skin becomes obvious in what Weber (1851) wrote, he postulated: "The sense of locality helps us better know the movements of our limbs and with the help of the movements of our limbs - dependent upon our own free will - we get to know our skin and orient ourselves on one and the same (the skin). Both abilities, from the beginning extremely limited, compliment and complete each other". The tangible and committing to tangible sensorial materials sharpen the senses and enables designers (everybody) to understand their environment through many sensory interactions and experiences. 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 (1996), 'Hands are underrated because they are poorly understood.' Weber (1851) stated that '...our sensory perception of the world is dependent upon the smallest measures which we possess and with which we can judge time and space.' To work with tangible materials (sensory-physiology approach) allows the designer to investigate and explore the constraints of materials in all its' splendor. Interaction with materials brings out creative sparks and imagination will follow suit.

In designing artefacts 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), 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. According to Charles Bell (1833) when treating the senses, and showing how one organ profits by exercise of the other and how each is indebted by that of touch, he observed that the sensibility of the skin is most dependent of all on the exercise of another quality. Without a sense of muscular action or consciousness of the degree of effort made, the proper sense of touch could hardly be an inlet to knowledge at all. The motion of hand and fingers, and the sense of consciousness of their action must be combined with the sense of touch. This means that having tangible materials as part of design processing is valuable since this gives real force-feedback and overall information about the overall design representation without the need of a haptic interaction device. The sense of touch is exercised by means of a complex apparatus - by a combination of the consciousness of the action of the muscles with the sensibility of the proper nerves of touch (Bell, 1833).

We need to interject common sense in merging traditional skill-sets, old-school technologies and new technology to develop new intuitive design tools that allow users (designers) free, un-tethered interaction while simultaneously allowing computational design to be a Virtual Design Assistant (VDA) in design engineering processing (Wendrich et al., 2009). Effects of tool use (both short- and long-term) have been provided by Schaefer et al. (2005). A person using a tool usually acquires a 'feeling' of the tool extensions, it has been hypothesized that the shape of the tool is incorporated in the body schema and might possibly affect the processing even in primary sensory (SI). Since tool use

is always associated with motor activity and requires elevated concentration at least during unskilled performance, it remains questionable whether changes in SI organization during tool use reflect rather effects of motor activity and attentional demands than an altered body schema (Schaefer et al., 2005). 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 3-D setting, rather than being restricted to mere 2-D projections for input and output.' The word 'natural' being used here is an anomaly in description since it is a virtual 3-D synthetic environment. To paraphrase Bell (1833), '...the motion of the fingers is especially necessary to the sense of touch. These bend extend, or expand, moving in all directions like palpi, embracing the object and feeling it on all surfaces, sensible to its solidity'. 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 modelling world.' We included haptic devices in our haptic perception (i.e. tactile and kinaesthetic) experiments to find out if this promise could be substantiated, effective, or helpful during design processing.

2.5 Tangible Representation as a Design Tool

The exploration and searching for new design tools through loosely defined projects, experimentations in materializing, creation of artefacts without pre-conceived notions, humanizing interaction tools of design, instigating tangible representation assignments in educational contexts and allowing topsy-turvy design solutions derived from 'nothing' materials brought us to further our quest towards human-in-the-loop computer interaction. We are working towards a hybrid solution, emphatic functionality combined with tangible materialization and a mere holistic form finding process. The shaping process as an ephemeral pleasure of ease-of-use, two-handed interaction with free forming capability assisted by ubiquitous computing bringing forth manual dexterity, serendipity in aesthetic manipulation and renewed enjoyment in hands-on design combined with digital virtual design tools. Design representation being integral part of design processing requires multi-disciplinary cooperation and willingness to re-think, re-adapt and re-make existing system-architectures and allow for more fuzzy-logic and irrationality in design representation. Our infatuation for digital technology strangles and restrains us too much to the extent that interjecting and including the natural intuitive expressiveness is smothered or wiped out. Harmony and symbiosis with nature and technology is prerogative.

2.6 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 5-phase design methods. 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. 9, right) of a design icon (Citroën DS) on A4 paper-format. 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. 9, 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, deliberating and thinking about their approach.

Figure 9. *Size Change (left), Orthogonal Drawing DS (right)*

Next thing they run off to the nearby photocopier to enlarge their drawing. This illustrates how difficult it can be to get grip on proportion and dimension. The scaled projections are being used as templates to ply and construct three (3) wire frames (Fig. 10) in aluminium wire, cardboard/paper strips and sheet metal strips. The wire frames have to conform to the enlarged drawings.

Figure 10. *Wire Frame DS (left), Paper Strip Frame (middle), Metal Strip Frame (right)*

It is a complex assignment because of the translation and transformation of two-dimensional elevation drawings into three-dimensional wireframe representations. Many questions and issues arise from this design process assignment. Key factor is making decisions, being a choice-architect and confrontation by designing-in-action, thinking-in-action and material-reflection. The final step in this assignment is to add surfaces or surface textures (Fig. 11) to the wire frame 'inspired by nature' to complete the project meaning to build shapes of seemingly great complexity. The object is to improve insight and learning 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 form and shape of an object. However, by allowing randomness in design processing the geometry will be jagged, but with a logic of its own and one that is easy to understand and identifies the idiosyncratic value of the object. In design ideation and conceptualization we support and look for unintentional change in processing, unpredictability in shaping and forming, being oblivious to blindspots, create variable contexts resonate intentions of design interactions and allow adversaries creating stories. Inadvertently we all inherent the same shortcomings, perceptive and sensorial problems and issues that come to the design workbench or computational design work station in multitudes of multiples where the need for ways of thinking on design and design science about design blindspots (See section 2.3) are sheer necessity and imminent.

Figure 11. Surface Texture examples on DS wireframes

2.7 Results Artefact Assignment

Two significant modelling methods emerged after evaluating and analysing the results of this experimentation, representation was either done by 3-D curves or by slicing. We based our findings on 36 selected models out of 150 individual iterations made by Bachelor students Industrial Design. The translation and transformation task is devised as a representational form study, finding and discovering aesthetic criteria, triggering aspects of form-giving and expanding the geometric vocabulary of novice designers.

Our goals:

- 1) Translating 2-D into 3-D transformation producing tangible form and shape
- 2) To discover differences in design approaches and form giving methods in 2-D to 3-D representation
- 3) Finding Form and Aesthetic Criteria in tangible objects
- 4) Exploring Form Structure that results from Form Organization
- 5) Enhancing Tacit Knowledge, Understanding and Imagination

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). The numbering is useful for interpretation purposes (Fig. 12).

Figure 12. Models in row, top left to right 1, 2, 3,...,34, 35, 36 (bottom left)

Modelling 3-D is about relations, proportions and distances between wires, views, surfaces etc. Correct distances between wires give the model the right proportions. Question arising from studying the models; if models are easier being translated proportionally using Figure A then Figure B? Our hypothesis is that the door lines in Figure A cut the image in three (3) pieces that have easier shapes to translate 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. B) the shape is much harder to analyse and translate, the shape appears lower and therefore could be transformed proportionally lower in the model.

Figure A

Figure B

Next to form and shape, we also had a closer look at detailing the model, some of the models show so little detail that consequently the level of proportion diminishes drastically. The chart (Fig. 13) shows the 36 models (line-up) with their corresponding level of detail. Each model in the chart shows the translating lines, the more the level of detail the better the result, proportional correct and shape enhancement. The models with a low level of detail correspond with the car shown in Figure B. We recognize the fact that in some cases the low detail level could stem from less motivated or engaged design processing.

Figure 13. Models and level of detailing

The interpretation of the 2-D orthogonal drawing determines the future result of the final model a sloppy or faulty process could have major implications. For example an incorrect interpretation which occurred frequently is that the central hood line (C) is not the same as the fender line (F) on the drawing (Fig. 14).

Figure 14. *Modelling and translating curves and lines*

The front and hood are difficult parts in shaping the model, in Figure 10 we show the correct corresponding lines to be used in a 3-D model translating it from the given drawings. Even in the front elevation is it hard to determine which lines should be used for translating (Fig. 15).

Figure 15. *Frontal and rear view of 2-D projection*

In this particular case a tangible 3-D 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. The result is that the front and hood become one piece without the characteristic separation between fenders and hood (See for example Fig. 16).

Figure 16. *Modelling and translating curves and lines of front and hood*

We extracted two main methods of modelling the 3-D objects from our selected line-up of 36 object iterations. Models were either made by use of the slicing method or through modelling with 3-D curved lines. With the slicing method the respective views from the orthogonal drawings are literally translated in the model. The top view becomes the base and is often the starting point of the model. All other elevations are translated and mounted onto the base. The side elevation is being used as a mid-section slice in most models (Fig. 17).

Figure 17. *Modelling by slicing method*

The finishing touch of modelling by slicing is the translation 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 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 translation 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. 18).

Figure 18. *Double use of elevation*

When modelling in 3-D curved lines the scaled 2-D drawings (view and elevations) are being used to create 3-D models. The chosen lines for executing the curved line model are not exact outlines or translated sectional views but flowing and fluent lines in 3-D space that cover more than one view or section (Fig. 19).

Figure 19. *Modelling in 3-D curved lines*

The designer has to have a good mental image, detailed insight and understanding of the total shape before commencing the modelling (Fig. 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).

Figure 20. *Modelling in 3-D curved lines*

2.8 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 creations of idiosyncratic artefacts. This made us aware of the huge array of possibilities and untapped potential in learning-by-doing, thinking-on-your-feet, knowing-in-action, the ambiguity in design sketching, abstract conceptualization and tangible representation. In our observations and in analysing the results we concluded that if we allow randomness, ambiguity and creative tinkering during the design process student designers were becoming true synthesizers. The combination of tacit knowing and tangible modelling as parallel congruous interaction gave way to enhanced results, more insight and understanding while at the same time evoking awareness, flow, passion, idiosyncrasy, self-esteem, sense-of-ownership, value and confidence. Other beneficial factors in this approach are visible signs of happiness, compassion, fellowship, sharing information, enhanced interaction and concentration. This means key factor is a practical learning context and freedom in creation being crucial to educational endeavour and bestow meaning, fluidity and responsibility.

2.9 Seven (7) Representational Design Experiments

We introduce seven (7) haptic representational configurations and set-ups. The participants get a brief set of instructions, design tools, an orthogonal projection of an artefact, a perspective template (size constraint) and five (5) minute time constraint.(action in time) We measure the effectiveness and other qualities between abstract and material representation by use of intuition, experience and tacit interaction. The aim is to acquire knowledge and make apparent the emerging inertia and entropy deriving from un-tethered and tethered tool use, stall, high learning curve threshold, tacit knowledge, routines, context constraints, signs of flow, gestures and skill development. The following benches were used in our research laboratory:

Figure 21. *Pencil Sketch Bench (left), Sand Sketching Bench (center), and Steam Sketching Bench (right)*

Figure 22. *Wire Plying Bench (left), Sculpting Bench with Formable mass (right)*

Figure 23. *Solid Works Bench (left), Virtual Clay Bench with haptic force-feedback device (right)*

Pencil-, Sand- and Steam sketch test benches are based on free-hand sketching, tacit knowledge and intuitive interaction. The participant has to create and visualize a 3-D perspective drawing of an artefact using only an orthogonal projection of an artefact. Duration of the tests is maximized to five (5) minutes. To test the methodology in these set-ups we measure effectiveness, ideation skills, visualization speed, apparent tacit knowing and threshold in learning curve. The data captured by video cameras will be analyzed and evaluated in conjunction with other datasets from other haptic experiments (Fig. 21). During Sand sketching the processing became 'hindered' by the randomly moving sand kernels and triggered the participant in faster iteration and intuitive interaction. During the Steam sketching sequence participants are engaged 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 made become almost invisible immediately after sketching and stimulate action, performance and flow.

The Wire Plying test bench is based on two-handed interaction and free form plying in aluminum wire, the participant has to create a 3-D wire frame of an artefact using an orthogonal drawing of the requested object. The time constraint is five (5) minutes whereby the use of tape, pliers and wire cutters is allowed. The transformation of 2-D projections to 3-D tangible wire frames brings out tacit knowing and enhances skill, touch and choice architecture. The two-handed Sculpting test bench stimulates the tangible experience of the participant the formable mass allows for fast and speedy iterations

and triggers the senses and imagination. Some wooden tools are being used during processing to create and allow some detailing. The methodology we test here is once again based on scaling 2-D projections to 3-D transformation into a tangible object. Duration of the test is five (5) minutes (Fig. 22).

The next two sets of experiments are based on digital representation tools, in the first procedure we engage the participant in 3-D CAD sketching using Solid Works. To lower the threshold in learning curve we provide a three-dimensional workspace including views and elevations of the artefact. The participant has to create a 3-D virtual representation of the artefact using the CAD tool and interaction device. The time constraint for this test procedure is five (5) minutes. In most cases we allowed more time for making the iterations in order to accommodate the user. The last test bench we offered is based on Virtual Clay in combination with a haptic force-feedback device. After a brief set of instructions the participant had to represent a 3-D virtual clay model from 2-D projections. We provided a block shape of virtual clay including views and elevations of the artefact to lower the threshold in learning curve and allow the participant to concentrate directly on the task. In many cases we had to allow for more time because of constraints in the tool or sensory perception problems in working with the haptic device. The duration of this procedure was five (5) minutes (Fig. 23).

2.10 Analysis Method and Results

We used Video Interaction Analysis (VIA) (Jordan & Henderson, 1995) to investigate the gestures, expressions, actions, immediacy (context), iterations and interactions with hardware and software. Video recording enables us to make qualitative analysis and evaluations of the various tests and test-results. Data was extracted from the video footage in the following order of test benches. We assessed 208 participant tests, students and experts, 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 during the testing and interaction, however, no further reference was made to the video camera during the assessments. The duration of the assignment was 5 minutes (effective), in some cases (test bench nr. 6 + 7) we allowed some additional time (± 10 min.) because of program inertia or high learning curve. Since we engage in ongoing experimental research, we decided to use a quantitative selection (Table I) of 83 participants and concluded provisional results from the selected raw data.

Table 1. Mapping and results video interaction analysis seven representational experiments (VIA) (selection)

Description	Pencil	Sand	Steam	Sculpting	Plying	3-D Solid	Virtual Clay
Number of participants	25	38	40	34	28	22	21
Total hi-speed test time edited	26:00	16:00	20:00	25:00	24:00	34:00	46:00
Real total video test time	3:28:00	2:08:00	2:40:00	3:20:00	3:12:00	4:32:00	6:08:00
Average test time/participant	08:19	03:22	04:00	05:53	06:51	12:22	17:31

The on-the-fly ideation of a design task and representing it either abstract or tangible showed us that experimentation with haptic interfaces is 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 convey higher end-output. Less demanding interfaces steam up the pace and create flow in interaction. Force feedback from material constraints transpires concentration and involvement in processing. 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 the result on the screen from their input. The following selections show the tangible and virtual results of the various test benches (Fig. 24 - 30);

Figure 24. Result Pencil Sketching-bench (selection) - <https://vimeo.com/10381990>

Figure 25. Result Sand Sketching-bench (selection) - <https://vimeo.com/10382551>

Figure 26. Result Steam Sketching-bench (selection) - <https://vimeo.com/10350603>

Figure 27. Result Wire Plying-bench (selection) - <https://vimeo.com/10382683>

Figure 28. Result Sculpting-bench (selection) - <https://vimeo.com/10351035>

Figure 29. Result 3-D Solid Work bench (selection) - <https://vimeo.com/10351195>

Figure 30. Result 3-D Virtual Clay bench (selection) - <https://vimeo.com/10351524>

2.11 Towards a Tacit Tangible 3-D CAD System

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, representing and design processing. The preliminary results and datasets from our experimentation procedures show that for ideation and conceptualization tacit and tangible iterations are easier, more direct, intuitive and faster than commonly available tools or methods. During ideation or creation of concept the ability to create, imagine and associate freely with abstract or tangible materials are considered dominant factors of the design engineering process. Bringing back the tangible, allowing tacit knowing and designer skills to emerge will lead to higher creative output in less time, while at the same time the Virtual Design Assistant stores the captured iterations by mimicking the tangible representations and storing them in a database as timestamps. The framework indicates the field wherein our (re)search is conducted (Fig. 31).

Figure 31. (Re)search Framework

After a thorough technology scan we came to the conclusion that the creation and development of a hybrid design tool would benefit the design and design engineering industry. The tool could be an excellent addition to the existing and emerging tools and methods by assisting designers in their physical and virtual design process. Our creation of a framework and technology scan (Fig. 32, 33) for analysing tangible interactions along a number of parameters and dimensions trying to understand and creating insight in the different levels of abstractions and similarities between the physical and digital representation activities. The framework allows us to explore novel devices in the design space, user's intuition, device and tool capabilities and underlying functionalities/semantics of CAD systems.

Figure 32. Physical and Digital Representation

Figure 33. Technology Scan (2010)

2.12 The Virtual Design Assistant and Tangible Workbench

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. 34).

Figure 34. Two-handed interaction (left) Virtual model from tangible interaction (middle) VR model with mesh iteration

The Virtual Design Assistant tool (VDA) or Rawshaping Formfinding tool (RSFF) stores and shows all the iterative steps as raw polygon meshes during the design representation process and places them in a solution space library. Real-time interaction or post-interaction with the various mesh iterations is possible with an un-tethered interface (multi-touch screen) that allows the user (designer) to interact intuitively with the polygon-meshes, blend them or synthesize the solutions. The possibilities

of inserting raw functional elements in design iterations leading to multi-layered manufacturing are strong and important features of this tool. The creation of a prototype of this hybrid tool (Fig. 35) and workbench for physical interaction (Fig. 38, 39) to stimulate intuitive and imaginative skills allow the designer more control, flexibility, flow in interaction, choice architecture, analogue tinkering, manual dexterity and allowing randomness. These elements are essential in behavioural- and robust interaction design along with the allowance of intuition and abstract and tangible notions. Commonly available tools and methods demands learning and practice before being valuable and reliable design systems. Some of these tools and methods have such high learning curves or constraints in mediation that users are getting de-motivated by the experience and start looking for other possibilities and tools to use. We recognize the importance of computational design and the increasing possibilities of emerging technologies, but we need to reconsider the human interaction approach and embed the significance of analogue tinkering and modelling in design processing. By starting in the creative or ideation phase (Fig. 36, 37) we respect the awareness, consciousness and idiosyncrasies of the designer instead of being confronted right from the start by 3-D digital modelling constraints and perceived affordance (ibid. HCI, D. Norman, 1990).

Figure 35. *Virtual Shaping Tool in Action - Polygon Mesh Iterations*

Figure 36. The Design Cycle

Figure 37. Ideation 3-D Physical

Figure 38. *Virtual Design Assistant Workbench*

The polygon-mesh iterations can also be used in cyberspace through Virtual Design Gaming (Kosmadoudi et al., 2014) between designers or design teams. For example, having VDA's on both ends of the playing/gaming field engages designers in multiple iteration and conceptualization contests (Wendrich et al., 2016c). Watch real-time interaction with HDT, follow this link: <https://vimeo.com/43850666>

Figure 39. *Designer + Virtual Design Assistant Engaged with Tangible Materials*

2.13 Summary and Conclusion

We should start from the fact that 'we can know more than we can tell'. Michael Polanyi (1966) 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). 'Abstract conceptualization now becomes something one can analyze and work from' (Finger and Asún, 2001). In Donald Schön's, *The Reflective Practitioner* (1983) he directs his attention to technical-rationality as a positivist epistemology of practice. 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 behaviour. 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).

We find that our educational experimentations, design method and system could provide a very useful platform for the development of new and more sophisticated design representation tools. Our aim to fill the voids between the analogue real and the virtual real by making use of tacit skills and traditional tools, an intuitive augmented workbench and common sense provided us with a huge array in data and information on design and engineering 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, insight and change while processing in the design context. To be assisted by a virtual computational device the design process in the ideation phase will be enhanced and improve the representational design process significantly. We continue working on synthetic computer environments that enhance the designer's seeing-drawing-feeling-sculpting, and provide a system that extends the designer's repertoire of physical and virtual prototypes, enhances their ability to explore them tangibly or virtually and bring them in transaction with particular design scenarios or concurrent designers. Our goal is to create an environment that helps the designer to discover and reflect upon his own design knowledge (For RST concept please view: <https://vimeo.com/51151019>). Our approach to create a Virtual Design Assistant (VDA) attempts to bridge the widening gap between the intuitive tangible and the virtual haptic reality.

RST Research Timeline

ABSTRACT

Design and Design Engineering is about making abstract representations often based on fuzzy notions, ideas or prerequisite requirements with the use of various design tools. In this chapter we introduce an interactive hybrid design tool to assist and support singular design activity or multiple collaborative creative processing and product creation. It enables the designer or design team to work smoothly with tangible artefacts and traditional design tools. It enables them to freely and intuitively manipulate these objects while simultaneously integrating the iterations into the virtual realm. By loosely-fitting the serendipitous objects, sketches, drawings, images and other data-sets of interest into the design creation process this hybrid tool supports the intuitive interaction and stimulates the immersive experience of mixed reality. The benefits of the system are haptic and intuitive physical interaction evoking the experience of semi-immersion during design activity. Furthermore the computational listing and repository of iterative history allows the users to access fallback choice-architecture, trackback decision-making patterns and make full use of the hybrid environment and design synthesis capabilities.

Categories and Subject Descriptors (according to ACM CCS): B.6.3 (Design Aids): Automatic Synthesis - Simulation

CHAPTER 3

Design Tools, Hybridization Exploring Intuitive Interaction

(This chapter is based on the peer-reviewed paper: "Wendrich, R. E. (2010, September). Short paper: design tools, hybridization exploring intuitive interaction. In Proceedings of the 16th Eurographics conference on Virtual Environments & Second Joint Virtual Reality (pp. 37-41). Eurographics Association.")

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3.1 Face-to-Face and Human Computer Interaction

We mimic, we reflect, we adapt ourselves continuously to our environment. Our senses are attentive, dose off or are triggered by impulses and cues from the world around us. We react and act according to our understanding and in some cases we move forward on a hunch. We adapt and comply willingly to change, and more often we do not accept change full-heartedly by rejecting the requested adaptation. Designers are known to change their minds continuously and in the spur of the moment being ambiguous in their choices and directions. During ideation and fabrication of full concepts the need for speed and fast iterations is a prerequisite to stimulate the creation process. Representations of ideas by creating abstract visual illustrations of mental models and through the devise of tangible working prototypes ideas are externalized and communicate spatial relationships within contexts (Brereton, 2004). Traditional analogue design tools still have a place in design representation and interaction, next to the digital design tools (Goldschmidt et al., 2004).

ANALOGUE	DIGITAL
FACE-TO-FACE AND BEST PRACTICLE LEARNING	BASIC ELECTRONIC ENTERTAINMENT AND COMMUNICATIONS
frontal lobes executive function	visual and motor
working memory, logic, insight, emotion and body language	sequential-short term memory
variable tempo	faster and faster
often - delayed rewards	immediate rewards
self - disclosure and openness	limited true self disclosure and anonymity
working memory	captivating graphics and sounds effects - stimulus bound - stimulus driven attention
working memory	simple memory
prioritizing	multitasking and continious partial attention

Figure 40. Comparison chart Analogue vs. Digital Interaction Environments

Face-to-face interaction (Hicks, 2010) between designers or multiple players play a strong role during ideation and working with sketchy information. To convey ideas and provoke thoughts by others we look at each other. This interaction between people creates a visual, nudging and tacit understanding (Polanyi, 1966) to evoke a mental picture of the given objective or design task (Fig. 40).

According to Don Norman (1998), we manage well in the natural world, interpreting the signs and signals of the environment and its inhabitants. Our perceptual system conveys a rich sense of space, created from the seamless combination of sights, and sounds, smells and feelings that surround us. Our proprioceptive system conveys information from the semicircular canals of the inner ear and our muscles, tendons, and joints to give us a sense of body location and orientation. We identify events and

objects rapidly, often from minimal cues - a brief glimpse or sound, for instance. But more importantly natural signals inform without annoyance, providing a natural, nonintrusive, nonirritating, continuous awareness of the events around us. Based on our research into distributed cognition and the sensory somatic aspects of interaction and behaviour combined with analogue and digital representation modes of communication, we developed and build the Loosely Fitted Design Synthesizer (LFDS) (Fig 41-left).

3.2 LFDS Setup and Functionality

The LFDS hybrid design tool consists out of a physical workbench fitted with a high-definition video web camera, a standard PC, and monitor. We devised special physical user-interfaces that intuit the user-interaction and a virtual user-interface to synthesize and visualize the captured content from user interaction. The 3-D workspace (sensorial space) allows for physical interaction with tangible materials, objects and real world tools. The monitor screen is the real-time virtual workspace visualizing the iterative workflow. As shown in Figure 41-right.

Figure 41. Setup LFDS and LFDS prototype

The LFDS prototype is used in experimental set-ups and real-world cases to study human interaction and human-computer interaction by integrating physical and digital artefacts in the workflow and capture the sessions and iterative content during design processing. The system is particularly suited to support and enhance group design work (collaborative design) when they explore the power of design and communication through physical prototyping or abstract presentations. However, single use of the system is also possible. The interaction takes effect the moment the video input is captured by the user by pushing the button (hand switch) or pedal (footswitch) to record an instance of the iterative process. The appearance and affordance of the switches are intuitively understood by the user. Easy input and data capturing stimulates and enhances the workflow. The instances are shown

real-time on the monitor in front of the user. The various iterations are either visible individually or stacked in piles. The layer structure of the instances keep the document stacks timed and historically linked (Wendrich, 2009 - 2010d). The users move through the workspace interacting with traditional design tools, paper, photographic images, and physical objects naturally and fluidly. However, digital data-sets (i.e. documents, CAD drawings, pictures) can be used as well. The real-time captures of the iterations simultaneously supported by the screen based system affords the use of both hands during interaction. Processing the iterative information goes uninterrupted and is augmented by the high-definition video camera capturing. The iteration are only stored when the actor physically (button push), makes the captures (see Fig. 42). In addition the system can also automatically capture the process as required by the user.

Figure 42. Capture button and capture foot pedal

The full control lies with the actor and the system assists in the creative process and affords the user to have decisive moments (Lehrer, 2009). To some level the multi-dimensional visuals (instances) are so intense and ‘life-like’ that the experience of immersion takes effect during interaction. This augmentation or semi-immersion is the benefit and contribution of this hybrid design tool. The instances and transformed instances are real-time visualizations on screen, see Figure 43. The layer-transparency, instant immediacy and active interaction in the physical and digital domain support the interaction, design flow and design processing (Wendrich, 2009 - 2010d).

Figure 43. Typical LFDS Iterative Instances as Visualized by the Hybrid Tool on the Monitor

Follow link for LFDS Tool Interaction and Functionality:

<https://vimeo.com/13462411>

<https://vimeo.com/15486159>

<https://vimeo.com/20834727>

<https://vimeo.com/132380605>

Figure 44. Numpad with icons explained

The iterations made within the interaction mode can be sorted, stacked, structured, selected and synthesized in the review mode as shown in Figure 43, 49 and 50. The instances are shown real-time on the monitor in front of the user. The various iterations are either visible individually or stacked in piles. The layer structure of the instances keep the document stacks timed and historically linked. With a special devised numpad, see Figure 44, the reviewing, choosing, tagging and selecting process by the users is afforded. A web based digital library (log in) has been added to save the interaction sessions and iterations. This allows the users to have access to their projects or sessions anytime and anywhere. Sharing and viewing the content or documents real-time is easy and affords to connect with other colleagues and/or stakeholders.

Through hybridization of traditional and digital design tools we combined the best of both worlds. The LFDS prototype is used in experimental set-ups and real-world cases to study human interaction and human-computer interaction (HCI) by integrating physical and digital artefacts in the workflow and capture the sessions and iterative content during design processing. The system is particularly suited to support and enhance group design work (collaborative design) when they explore the power of design and communication through physical prototyping or abstract representations. However, single use of the system is also possible.

3.3 Linking the Real and the Virtual with LFDS

The hybrid interface of the LFDS with a recognizable physical workbench and 3-D sensorial space includes a standard pc or laptop and electronic tools - intuitive haptic buttons, high-definition camera, monitor and wireless numpad. The Real World and the Virtual Reality are clearly merged (Fig. 46). The tangible-tacit interface combined with virtual assistance can be seen as a continuum of knowledge space which goes from knowing nothing about the interface to knowing everything someone could possibly know (Spool, 2005). There are at least two points that interest us most; knowing the Current Knowledge of the user when they first approach the interface and secondly the Target Knowledge the user needs to accomplish the task, as presented in Figure 45 left and right. The tangibility of the LFDS system affords the distribution of meta-cognition and places the user in the centre of this Knowledge Gap. The user knows and is familiar with the physical world, design processing and iterations happen when users already know things (See also Chapter 5.2.3).

Figure 45. *The Current Knowledge (left) and the Knowledge Gap (right) of interfaces*

A facilitated comfort zone makes the user relaxed and focused on the task to complete. The user will move through the workspace interacting with traditional design tools, paper, photographic images and physical objects naturally and fluidly (Schön, 1992). However, digital data-sets (i.e. documents, CAD drawings, pictures) can be used as well. The real-time captures of the iterations simultaneously supported by the vision system affords the use of both hands during interaction. The hands being the ‘instruments of the mind’ (McCullough, 1996) allows the designer to investigate and explore the constraints of materials in all its’ splendor. Interaction with materials ignites creative sparks, and the imagination in the brain will follow suit (Schön, 1992), (Wendrich et al., 2009).

Figure 46. *The two-worlds challenge: linking the physical and the virtual*

Processing the iterative information goes uninterrupted and is augmented by the high-definition video camera capturing. The iteration are only stored when the actor physically (button push) makes the capture. The full control lies with the actor and the system assists in the creative process. By decreasing or reducing complexity the amount of knowledge needed by the user will change, the user interface will need less target knowledge (Spool, 2005). To some level the multi-dimensional visuals (instances) are so intense and 'life-like' that the experience of semi-immersion takes effect during interaction. This augmentation is the benefit and contribution of this hybrid design tool. The instances and transformed instances are real-time visualizations on screen. The layer- transparency, instant immediacy and active interaction in the physical and digital domain supports the interaction, design flow and design processing.

3.4 System Infrastructure and Process

We built and devised the system on commercial-off-the-shelf (COTS) components to produce a low-cost/high-value and affordable hybrid design tool system. We use a standard Windows PC with XP, 7, 8, 10 OS and Input and Output Devices to support the interaction. The software is programmed making use of Open Source platforms. The programming language used is haXe (haxe.org) together with Neko and Screenweaver HX (screenweaver.org) of which the haXe code is compiled to Flash-files for the graphical environment. The save files are in XML format (Fig. 47).

Figure 47. Hybrid Architecture of the non-immersive LFDS

3.5 LFDS: Hybrid Design Tool

The Loosely Fitted Design Synthesizer (LFDS) has a strong metaphorical link with a design office inspirational pegboard, picture wall or serendipitous image-wall (Fig. 48 and 49).

Figure 48. *Serendipity Inspiration Wall in Real World Design Environment*

This kind of raw data repository with clippings, image collections and paraphernalia of trivial objects clutter the office wall and desktops as a token of memories and tell time in historic layers. These artefacts or objects combined, embody a certain serendipitous value and provoke creative ignition in support of ways of thinking on design and/or design articulation. On-line searching for inspirational content has similar cognitive triggers. The LFDS has connections to both this analogue wall and the digital wall of sites like e.g. Flickr, Google and Instagram images. A great example is the web-based Loosely Fitted Image Synthesizer (LFIS, 2016): <http://rawshaping.com/r/lfis>

Figure 49. *Iterative Instances Stacks in LFDS Hybrid Environment in Digital Realm*

If we consider the Iterative Stacks as a result of a design process meeting, we can imagine that in the course of this meeting, several players or stakeholders actively presented their ideas and thoughts on the project at hand. Verbal, narrative, and visual information analogue or digital is spread openly and shared among the different participants and/or stakeholders during the meeting. The use of gestures, speech, annotations (real and virtual), abstract and exact data will go crisscross from player to player. At the end of the session the players or stakeholders are able to trackback their process and follow the decision-making steps in the listing. The stacks can be sorted in order of importance or functional organization. All the players have access to the digital data and iteration stacks and are able to replay or recall meetings and report on them to other stakeholders, departments or colleagues (Fig. 50).

Figure 50. *Iterative Instances Stacked top left (refer arrow) and Loosely Fitted Iterations (right)*

Important stakeholders or other players that were not present can benefit this way from the virtual visual data-stacks that were generated by the system during the meeting. All the stacks can be loosely-fitted together and stacked in order of agreements made, high-priority topics or otherwise to fit the wishes and demands of the participants or stakeholders. The LFDS can be used as a presentation tool for the next meeting or can be adapted for a specialized meeting for engineers, process managers or others. The various iterations can be printed 2-D as a visual representation or fed into the design processing loop as a tangible. To have sharing technology available instantly could be an important feature in collaborative settings. The ability to share the real-time interaction on-line in conjunction with a web application (e.g. Skype, WhatsApp, Google, HumHub, Noodle) is tested during our experiments and showed promising results. Test the webbased LFDS version (Beta) here: <http://rawshaping.com/r/lfdsw>

3.6 Conclusion

The LFDS system gives promise to intuitive physical interaction (hand and foot) and readiness in terms of real-time interaction transformed into digital information. Our on-going (re)search on synthetic computer environments will enhance the designers' tacit and tangible activities, and extend the repertoires of physical and virtual representation. Our goal is to create tools that work and environments that assist and support the designer to discover and reflect upon his/her own design knowledge and experience. At the same time bring this know-how and experience in contact with other designers, stakeholders or other disciplines. The results with the LFDS tested in real-world cases are promising and lead to further development of the tool.

ABSTRACT

Design and engineering in real-world projects is often influenced by reduction of the problem definition, trade-offs during decision-making, possible loss of information and monetary issues like budget constraints or value-for-money problems. In many engineering projects various stakeholders take part in the project process on various levels of communication, engineering and decision-making. During project meetings and VE sessions between the different stakeholder's, information and data is gathered and put down analogue and/or digitally, consequently stored in reports, minutes and other modes of representation. Results and conclusions derived from these interactions are often influenced by the user's field of experience and expertise. Personal stakes, idiosyncrasy, expectations, preferences and interpretations of the various project parts could have implications, interfere or procrastinate non-functionality and possible rupture in the collaborative setting and process leading to diminished prospective project targets, requirements and solutions.

We present an Industrial case-study incorporating hybrid tools as Virtual Assistants (VA) during a collaborative Value Engineering (VE) session in a real-world design and engineering case. The tool supports interaction and decision-making in conjunction with a physical workbench as focal point (-s), user-interfaces that intuit the user during processing. The hybrid environment allows the users to interact un-tethered with real-world materials, images, drawings, objects and drawing instruments. In course of the processing captures are made of the various topics or issues at stake and logged as iterative instances in a database. Real-time visualization on a monitor of the captured instances are shown and progressively listed in the on-screen user interface. During or after the session the stakeholders can go through the iterative time-listing and synthesize the instances according to i.e. topic, dominance, choice or to the degree of priority. After structuring and sorting the data sets the information can be exported to a data or video file. All stakeholders receive or have access to the data files and can track-back the complete process progression. The system and information generated affords reflection, knowledge sharing and cooperation. Redistribution of data sets to other stakeholders, management or third parties becomes more efficient and congruous. Our approach we took during this experiment was to (re)search the communication, interaction and decision-making progressions of the various stakeholders during the VE-session.

CHAPTER 4

A Novel Approach for Collaborative Interaction with Mixed Reality in Value Engineering: A Case Study

(This chapter is based on the peer-reviewed paper: "Wendrich, R. E. (2011, January). A Novel Approach for Collaborative Interaction With Mixed Reality in Value Engineering. In ASME 2011 World Conference on Innovative Virtual Reality (pp. 103-111). American Society of Mechanical Engineers.")

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4.1 A Case Study with Hybrid Design Tools: LFDS

The definition and solving of problems that originate from design and engineering projects are a major part of the process. To concurrently make the right decisions in accordance with specific requirements and target expectations is most of the time organized and orchestrated within stakeholder meetings. Results, reductions and conclusions made by the different stakeholders in the process should be reliable and fitted solutions to complete the project successfully. The decision making during a real-world collaborative value engineering session is the foundation for this (re) search and experimentation with a prototype of a hybrid design tool. We tested and explored the interaction, assessment and communication between the various stakeholders in a use-case named; Project Alkmaar Railway Station 2015 shown in Figure 51.

Figure 51. Artist impression Station Alkmaar

The current re-design, construction and development of this station, involving a large number of different stakeholders, presented an opportunity to investigate and evaluate user-interaction, intuition, decision action, face-to-face communication, behavioural aspects and action feedback. The project is managed by ProRail BV in Utrecht, the Netherlands, and also includes the following stakeholders; Dutch National Railways (NS), Municipality Alkmaar, Movares Engineering BV and a Design Consultancy. The tool set-ups we created especially for this session consisted of a multiple workbench and during the course of the session we changed it into a single workbench. The object of this Custom Value Engineering (CVE) was to reach commitment and understanding between all of the seven (7) stakeholders on the project issues at hand. Topics were; budget, cost-value ratio, ambition level, common ground and integration of the different stakes. In an earlier analogue VE session, some major issues were not resolved or concluded, leaving some interesting components of the projects open for discussion and further debate. In close cooperation with ProRail BV, we took the approach to introduce the Loosely Fitted Design Synthesizer (LFDS) user-interaction tool to the VE session, embedding Mixed Reality (MR) in the collaborative environment. The hypothesis being that the possibility to real-time capture all relevant actions, iterations and project data during the sessions the participants could afterwards reflect, track-back and get feedback support from the system. Showing all the specifics, wishes and requirements on the project in listing and become ready available for assessment, analysis and evaluation by each stakeholder individually or team by accessing the logged data base.

4.2 Custom Value Engineering with LFDS Setup

VE is a systematic method in design engineering to improve the cost-benefit ratio, reducing costs, increase productivity, and improving quality. In this case we focus on two specific items of the design and construct phase for Project Station Alkmaar. Two main parts were addressed during this session were; the passage way connecting the North and Centre areas and bicycle storage facility, shown in Figure 52.

Alkmaar stationsgebied

Plattegrond

ProRail III 23

Figure 52. Site plan Station Alkmaar

VE here defined as function analysis of buildings, facilities, infra-structure, performance, design, reliability, safety, and environment. The process steps to find the 'best value' in relationship to cost and ambition. Ambition described as in combination of Function, Convenience, and Aesthetics. LFDS in support of collaborative stakeholder interaction showed promise and affords intuition, creativity, brainstorming, and naturalizing intention in action. We chose to start with two physical workbenches as shown in Figure 53 and Figure 55, with two separate hybrid systems to facilitate the group of seven stakeholders, three expert invitees, one facilitator (Value Engineer), one designer, and four (re)searchers of Rawshaping Technology (RST). After a brief introduction of the hybrid tool and the project scope the VE session commenced.

Figure 53. *Typical single LFDS setup with various stakeholders*

The facilitator directed the process initially to stimulate, give instructions and trigger the interaction. During the course of the process the two groups worked on the various tasks and issues, standing on their feet discussing and manifest ideas scribbling peg-words (Worthen et al., 2011) on post-it notes with markers to identify and remember target information. In this scenario the stakeholders rely on their tacit and explicit knowledge, bringing their expertise to table and to make these manifest. All to-be remembered items are thus organized serially by virtue of association with loosely structured order and captured by a push on the red capture-button interface. The iterative instances are manifest real-time on a monitor and cue the users during the interaction. The various instances are listed (time-line) and users (participants) are able to navigate the iterations with a special user-interface (numpad). Direct visual system feedback affords to synthesize, review, select, sort or structure the captured data-sets. All content is logged, mapped and stored in a data base to be retrieved or exported on demand. In a second set-up we created an extended workbench, see Figure 54 and Figure 56, with one hybrid system to semi-immersed the complete group of stakeholders. In this session we introduced

photographic material, artist impressions and site plans of the project. The idea behind this was to stimulate the interaction in defining the problems, finding solutions based on design requirements, ambitions and wishes of the stakeholders. The hybrid tool assists and supports the participants in un-tethered two-handed interaction with tangible materials and drawing instruments, and enhances face-to-face communication. The hybrid tool becomes a focal point during user-interaction where the users-in-the-loop can freely move around the workbench and take active part in the project discussion. Thinking-in-action and participating dynamically stimulates brainstorming and has direct influence on the participative role of the stakeholder (individual). According to Minneman (1996), there are shortcomings with most current collaborative technology, especially used to interact with spatial content. In face-to-face collaboration, people use speech, gesture, gaze and non-verbal cues to attempt to communicate in the clearest possible fashion. Minneman (1996) continues to argue that in many cases the surrounding real world or real objects play a vital role, particularly in design and spatial collaboration tasks. Physical objects support collaboration both by their appearance, the physical affordances they have, their use as semantic representations, their relationships, and their ability to help focus attention. Real objects are also more than just a source of information, they are also the constituents of the collaborative activity, create reference frames for communication and alter the dynamics of interaction, especially in multi-participant settings (Minneman, 1996). Our hybrid tool system affords the tangible real-object paradigm while simultaneously supporting the interaction with screen based virtual objects or in our case virtual instances and iterative stacks. To paraphrase Billinghurst (2002); '...collaborative AR interfaces can produce communication behaviours that are more similar to unmediated face-to-face collaboration than to screen based collaboration. This is because when people collaborate at a table they can see objects on the table at the same time as each other, thus the task-space (the space containing the objects) is a subset of the communication space. However when users are collaborating in front of a screen the task space is part of the screen space, and may be separate from the interpersonal communication space. Thus, while unmediated face-to-face collaboration and AR interfaces support seamless interaction, the screen-based interface may introduce a discontinuity that causes collaborators to exhibit different communication behaviours. In a recent experiment we explored this by comparing communication behaviours used to complete logic puzzle tasks in three conditions:

- face-to-face collaboration with real objects
- co-located AR collaboration with virtual objects
- co-located projection screen based collaboration with virtual objects

The virtual objects were exact copies of the real objects and in the AR case, they were attached to real objects so that Tangible AR manipulation techniques could be used... (Billinghurst et al., 2002). According to Billinghurst implementing a workbench or table approach has merit to support seamless interaction. Instead of using strictly AR in our interfaces, our focus is on physicality and tangible interaction supported with virtuality. The notions stated by Billinghurst apply also to our virtual assistant coupled within a MR environment. In our second test set-up the participants showed more congruous interactivity and created more insight and understanding between the different stakeholders. The role of the facilitator during the CVE session became increasingly more important when working with divided work areas compared to the use of a single workspace. In the former the facilitator had to maneuver between the two groups and try to maintain process flow on the prospective targets. In the latter the facilitating of the process progression was more fluid and natural intuitive.

Figure 54. *Extended workbench LFDS*

4.3 Hybrid Design Tool and Interaction

We base our (re)search on the notion that two-handed physical interaction is important to stimulate the brain and processing of information tacit and/or explicit. Trigger intuition and intention-in-interaction with tangible representation enables improvements in perceptual skills. Rosenblum (2010) argues that the more you touch, the more your brain changes. Intensive practice with touch can change the organization of your brain's touch areas (somatosensory cortex). Touch experiences enhances touch sensitivity and tangible tasking leads to short-term plasticity to establish long-term plasticity. By enabling the user to manifest ideas or notions physically (two-handed) intention-in-action is activated. Within the context of this experiment we observed that sketching, pointing, and grasping hand actions suggested the intentions clearly of the various participants. No need to make explicit beforehand, suggesting that others intrinsically understand intentionality of action (Grammont et al., 2010). Thereby evoking and enhancing interaction, intention and behaviour within the others to mimic and make representations also. The physical and virtual interaction enforces the cooperative process, collaborative progression and procedures defining and assessing possible solutions. To afford the capture of representations with a tangible red push-button intuit the user (-s) decision-making process. The real-time virtual simulation is a functional process that processes certain content, typically focusing on possible states of its target object. Analogue physical experiences from distributed cognition are essential in staying in touch with reality, while at the same time using virtual reality to further and broadening the scope of these experiences. Another beneficial factor of the hybrid tool environment is the face-to-face interactivity. Nothing in the perceptual world communicates so much information so quickly as a human face (Rosenblum et al., 2005). From a face, you can rapidly determine an individual's identity, gender, emotional state, intentions and so forth. Faces convey more subtle personality characteristics and simply recognize the idiosyncratic ways of the persons move their face. During the session we observed and analyzed this activity between the stakeholders to map the influence on behaviour, emotion and collaboration in the VE process. The approach we take with

the hybrid design tool is a symbiosis of the two-world-challenge, between the physical and the virtual realm. Furthermore, we could add that the five key features of collaborative AR or MR environments are identified (Schmalstieg et al., 1996);

- Virtuality:* Objects that don't exist in the real world can be viewed and examined.
- Augmentation:* Real objects can be augmented by virtual annotations.
- Cooperation:* Multiple users can see each other and cooperate in a natural way.
- Independence:* Each user controls his own independent viewpoint.
- Individuality:* Displayed data can be different for each viewer.

4.4 Synthesis with Mixed Reality

Making maps and making images is unquestionably the primary function of human brains, it is hardly their most distinctive feature. The distinctive feature of brains such as the one we own is their uncanny ability to create maps. Mapping is essential for sophisticated management, mapping and life management going hand in hand (Damasio, 2010). Damasio continues to argue that, when the brain makes maps, it informs itself. When brains make maps, they are also creating images, the main currency of our minds. Ultimately consciousness allows us to experience maps as images, to manipulate those images, and apply reasoning to them. Maps are constructed when we interact with objects, such as a person, a machine, an environment, from the outside of the brain towards its interior. The hybrid tool we present is a direct analogy on the aforesaid, creating visual representations through interactions in a collaborative environment, thereby creating a rich pallet in imagery and iterations instigated by physical and mental action. According to Damasio (2010), the human brain maps whatever objects sit outside it, whatever action occurs outside it, and all the relationships that objects and actions assume in time and space, relative to each other and to the mother ship known as the organism, sole proprietor of our body, brain, and mind. The human brain is a mimic of the irrepressible variety. The LFDS suggests mapping and rendering visual imagery in time and space that can be (re-) arranged, sorted and structured in maps of serendipitous variety or fashion. The LFDS assists the user by mimicking the mental process within a virtual solution space, thereby offering support in transformation and manipulation of content. The synthetic quality of the program allows the user full control over the iterations, choice-architecture, priorities and importance of the iterative progressions. The aim of the LFDS is to make user-interaction in synthetic environments more real, visceral and transcendent by embedding the virtual in the real. We stimulate visual thinking, imagination, creative tinkering, sketching, and follow the visual thinking process of Look, See, Imagine, and Show (Roam, 2009). We may have imagined fantastic ideas, but unless we have a way to show them to others (sharing) the value of our ideas will never be known. Sharing ideas, notions and expertise in collaborative value engineering session implement our novel approach to support the narrative and oral communication with a hybrid design tool showed promise.

4.5 Experimental Setup Case Study

The experiment was setup at the facilities of ProRail BV in Utrecht, the Netherlands. For the experiment we created two LFDS hybrid design tool systems that worked independently from each other. Special modular workbenches were made for easy installation and reconfiguration of the setup as illustrated in Figure 55 and Figure 56.

Figure 55. Typical LFDS setup experiment CVE

We offered various tangible materials, drawing instruments, maps, plans, artist impressions, photos of the present site and environment. Abstract representation and negotiation with tangibles showed natural interaction between stakeholders, sharing knowledge, lively ideation and conceptualization cumulated in several data-sets. We observed the emergence of story-telling especially in the second part of the session where we changed to a single workbench setup. According to Damasio (2010) one of the problems of how to make all the wisdom understandable, transmissible, persuasive, enforceable, we concluded storytelling was the solution. In a socio-cultural context narratives are extremely important factors for success and benefit the communicative process. The best decisions emerge when a multiplicity of viewpoints are brought to bear on the situation (Lehrer, 2009). The workbench can be seen as focal point, wherein the participants acted freely, interacting intuitively, sharing explicit knowledge, and express expert information. Although we tend to think of experts as being weighed down by information, their intelligence dependent on a vast amount of explicit knowledge, experts are actually profoundly intuitive (Lehrer, 2009). Lehrer argues further, that an expert evaluates a situation he doesn't systematically compare all the available options or consciously analyze the relevant information. He doesn't rely on elaborate spreadsheets or long lists of pros and cons. Instead, the expert naturally depends on the emotions generated by his dopamine neurons. His prediction errors have been translated into useful knowledge, which allows him to tap into a set of accurate feelings he can't begin to explain. The best experts embrace this intuitive style of thinking. The best decision- makers know which situations require less intuitive responses.

Figure 56. Typical extended setup LFDS experiment CVE

Working with the hybrid design tool evoked and enhanced enjoyment and fun during collaborative interaction we observed spontaneity, laughter, and animosity, during the course of the experimentation. Notably in the extended setting most of the stakeholders were immersed in activity, participating fully in the process, stepping up to the workbench, falling back to a reflective stance followed somewhat later by an explicit remark or interjectional notion. Partly we dedicate this phenomenon to the novelty of working with a new tool in a known framework, however quite possibly the positive ambience was ignited by this novel mode of working together.

4.6 Results CVE Session with LFDS

In the following images we present a selection of the iterative instances captured during the CVE session. A great number of iterations were logged and stored by the systems in the initial setup (dual setup) however they were considered mere copies of posting peg-words on a canvas than results from intrinsic interaction activity. The results shown in Figure 57 and 58 clearly show this.

into another target direction. The group of stakeholders appeared more together and showed more connectivity in interaction. We observed idiosyncratic individual behaviour, characteristics and signs of dominance during the CVE session. We assume that every stakeholder has its own place in the group dynamics according to role, stake, position, expertise and communication skills. Furthermore, we can deduce that a collaborative setting has strong socio-cultural patterns and various levels of psycho-physiological behaviour. The results shown in Figure 59 and 60 (*See also vimeo links*) represent a variety in solutions for specific parts of the envisioned project.

Figure 59. Collaborative tangible interaction with LFDS

The level of detailing and target specific call-outs in the proposed and possible solutions, illustrate the intrinsic cooperation between the stakeholders. Interactions with the system, capturing instances of the sketches and abstractions intensified towards the last hour of the CVE session. The observations and interpretations of real-world problems and needs clarified in this CVE experiment and real-world case-study is translated and manifest to a large extent into a visual definition of requirements. The procedures are performed at a very conceptual and abstract level, but as the design and engineering process progresses, the focus of 'defining and assessing solutions' shifts towards more detailing leading to final execution and results.

Follow these links and watch the CVE sessions online:

<https://vimeo.com/16997579>

<https://vimeo.com/16998018>

<https://vimeo.com/16998789>

<https://vimeo.com/17004503>

<https://vimeo.com/17005888>

Figure 60. *Interaction and Representation*

Figure 61. *Virtual instances on screen*

In the course of the project process adaptations according to new insights gained are defined. The stored iterative instances form a solid basis for trackback, retrace decisive moments, feed-back, and reflection on ideas and conceptual notions. All stakeholders in this case-study have access to all the generated content of the CVE session (Fig. 61). The observations and results from the sessions were analysed and evaluated based on the acquired data from the HDT's, observations (e.g. gestures, interactions, behaviour, performance, pleasure, expectations etc.) from the video analysis and by conducting interviews directly after the session with all the stakeholders. Furthermore, feedback from all the actors were noted and were informed to us spontaneously during the informal get together after the sessions had been concluded.

4.7 Conclusion

CVE is a process where value is set-off in direct relation to budget and exploring the possibilities and feasibility in reaching the projected and targeted ambition. In this experimentation and real-world case-study we observed stakeholder interaction during iterative process. We tested two configurations and captured instances during project progression. Goals, targets and specific requirements were defined by user-interaction actively using the LFDS hybrid environment. Division of the hybrid workbenches had a direct affect and effect on the users, the facilitator and the resulting data. After re-configuration the group of stakeholders seemed more congruous and interaction was more intrinsic and lively. Concentration levels and focus became significant higher which in turn stimulated the iterative process. Captures were made in close cooperation and supported the decision-making process. In the evaluation with the seven stakeholders we noticed a very positive attitude towards working with the hybrid tool. In some cases the participants noted that the system showed promise but they expected more. A strong point of working with the hybrid system is direct face-to-face communication and record instantly iterations in a visual mode. Furthermore, making annotations and comments in direct confrontation with each participant also was mentioned as a beneficial factor. One of the major issues in this particular case-study was the search and exploration of common ground in the definition of value in relation to the projected ambition (Function-Convenience-Aesthetics). Besides the collaborative aspects, this CVE session contributed also in the creation of insight in the complexity of the project. According to the participants most of the issues addressed became more transparent, which for a large was contributed to the hybrid system. Generating alternatives and direct visualizations of choice-architecture by embedding the expected customer experience in the value engineering process contributed to the process. Working with instances in this manner enhanced the user-interaction experience, although most participants remarked that a certain newness and alienation at the beginning of the session created some interruption. Some indicated that the facilitator had to be more specific and directional during the CVE process. User feedback (See [Appendix D](#)) showed that a specific advantage of the hybrid tool is users being enabled to manifest everything that is generated (See also vimeo link: <https://vimeo.com/178181528>). Picking up a marker, post-it note to sketch or write down notions and ideas were contributed to working with the system. We observed that imagination and creativity was stimulated by the interactivity and visualization on screen, some participants indicated the mode of interaction evoked more insight and understanding. Most users indicated that they needed another session with the hybrid tool to really make full use of the capabilities. They should have had more time to prepare and structure their content before their participation in this CVE session. They saw merit in the novelty of the procedure and retracing of process progression. They recognized the fact that a lot of information gets lost during regular meetings, VE sessions, in daily interaction and business dealings. In future setting the participants indicated that starting with a single unit could be helpful to start processing. This setup should than change and followed up by separate smaller groups divided on several workbenches. Stronger emphasis should be put on reviewing the sessions and choice architecture processing. For traditional VE processes at ProRail and in combination with HDT's follow these links:

<https://vimeo.com/176170254>

<https://vimeo.com/176170247>

<https://vimeo.com/176170246>

RST Research Timeline

Keywords: Design, Design Engineering Processing, Hybrid Design Tools, Mixed Reality, HCI

CHAPTER 5

Hybrid Design Tools for Design and Engineering Processing & Case Study

(This chapter is based on the peer-reviewed book chapter: "Wendrich, R. E. (2014). Hybrid Design Tools for Design and Engineering Processing. In Advances in Computers and Information in Engineering Research, Volume 1. ASME Press.")

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5.1 Background: Human Empathy and Sensory Deprived Computers

In 2004 we conducted a research survey with students industrial design engineering and engineering technology in our university. The study was aimed to investigate the future possibilities of virtual reality in design, engineering, and formgiving. After quantitative analysis the most significant findings were that incorporating virtual reality in design systems had to follow; ease-of-use; simple effective control; intuitive untethered interaction; real-time feedback; and high-definition visualization to establish more insight and enhanced understanding. One interesting aspect of this survey was the fact that abstract representation (visual) had pre-dominance over physical representation (tangible). Our preliminary conclusions pointed us towards a hybrid tool that affords a continual challenging between visual and tangible representation illustrated in Figure 62 (adapted from McCullough, 1996).

Figure 62. *The two-worlds challenge: linking the physical and virtual realms*

In turn this could enhance and refine the process as long as the user feels that the tool serves intent, bring out capacities for action, stimulate intuitive interaction, and accommodates mixed reality modalities. Pailhous et al. (2010) argue that, '... an excess of intellectualization (computation, representation) with its consequences for the supposed brain organization splits humans from their childhood and the human species from its origin, gregarious among others. In order to be empathetic, we first need to avoid being totally empathetic; otherwise, we would simply be in symbiosis, and, then, how could we attribute an intention to anybody without having the possibility not to be the agent?' We concur with Clark (1999) that perception⁶ and action are interconnected at a structural level. According to Jeannerod (1986) it has been shown that actions are organized specifically according to their goal: the grip aperture is specifically correlated to the size of the target object. The execution of a simple grasping action implies taking into account not only the properties of the motor system but also the properties of the object that are relevant for the action: its size, shape, texture. A tool for example may not only perform some action, but may also come to represent that action. A tool is inscribed in your imagination not only as an activity, but also as a symbol (McCullough, 1998). In a sense we can say that it is a pragmatic representation of the object (Jeannerod, 1994). These two conditions (perception and action) suggest that there are not only two types of visual perception, one to identify and the other

⁶ 'Touch is not a single perception, but many instead, then its purposes are also manifold.' - Aristotle (384-322BC) *De Anima*

to localize, but also two types of action, one descriptive and the other operational (Legrand, 2010). However, things are not so simple as might be construed here. The notion of constructing a tool based on perception and intention in action has also fundament in learning-by-doing, knowing-in-action, reflection-on-action, and thinking-on-your-feet as demonstrated in Schön (1983, 1992). Brereton (2004) described this as distributed cognition in engineering design as such that negotiation between abstract and material representations are instrumental to thinking. Employing a physical prototype in a real context of use often reveals unanticipated information, which is one of the strength of physical prototypes. Material representations are external representations, the ability to reconfigure and reinterpret material representations is where their power lies in helping designers to think and learn (Brereton, 2004).

5.2 The De-skilling Effect in Design and Engineering

A main task of designers and engineers is the shaping and transformations of ideas or fuzzy notions into abstract or materialized equivalents. These sketches, models or other representations can be described as the sum of form and shape aspects, aesthetics, intuitive qualities as well as technical and sustainable functionalities. The designer or engineer must understand the elements involved in this synthesis of form giving, design and functional elements. Successful designers or engineers compose these characteristics carefully and join them together to form and shape artefacts into a harmonious and balanced whole, while simultaneously maneuvering within implicit and explicit mechanical and functional aspects. With the emergence of 3-D computational design, the design process shifted from traditional analogue physical representations of ideas or artefacts to digital virtual realities. This shift created a pre-dominance of digital design over the idiosyncrasies of analogue craftsmanship of the designer. Loss of control, immediacy, manual dexterity and skills due to constraints, high learning curves in electronic interfaces (e.g. WIMP) and programmer's directions, gave way to alienation of the physical material world. Lanier (2010) describes this phenomenon as follows: The deep meaning of personhood is being reduced by illusions of bits. Since people will be inexorably connected to one another through computers from here on out, we must find an alternative. The last decades showed a plethora of tools and tool interaction that eluded many users, consequently leading to misinterpretation, frustration, reduction and inert mediocrity. This is not to speculate that digital innovations and tools are defunct gadgets or not worthy of inclusion in daily life. On the contrary, digital technology⁷ plays a crucial role in our understanding of the physical and virtual worlds that co-exists and give us a much broader and boundary less experience and perspective than ever before. The problem with most digital tools is the often non-intuitive interface (uncanny sieve) between the user and the machine, much study and research has been conducted on this subject over the last decade. The empirical research and exploration we conduct in tool use in product/design creation processing (PCP) places in perspective studies and concepts of design processing as conducted by e.g. Schön, 1983; Brereton, 1994; McCullough, 1996; Minneman et al., 1996; Billinghamurst et al., 2002; Bergamasco et al. 2002; Woolley, 2004; Ishii et al., 2004; Bordegoni and Cugini, 2006; Sener et al., 2005-2007; Robertson et al., 2009; Wendrich, 2010a,b,c,d; Wendrich, 2011b,c; Bertran, 2010. Moreover, Lanier (2010) argues that the deep meaning of personhood is being reduced by illusions of bits; people degrade themselves in order to make machines seem smart all the time. However, every instance of intelligence in a machine is ambiguous. Virtual reality, for instance, was built to make this world more creative, expressive, empathic and interesting.

⁷ *Technology is at its best when it is invisible.* - Nassim Nicholas Taleb (2010)

5.2.1 Merging Tangible and Virtual Modelling

In our approach to author and build hybrid design tools, we focus on the human perspective including all their idiosyncratic characteristics, inherent skill-sets, intuitive qualities, tacit knowledge, life experiences and often perplexing ambiguity combined with the human capacity to learn, acquire knowledge and enhance skills. Furthermore, multi-sensorial perceptions and feelings are dominant aspects of human experience as are memories and imagination. Distributed metacognitive interactions with predetermined or loosely defined constraints are essential to manifest ideas, explore fuzzy-notions and stimulate inventiveness as presented in Figure 63 (Wendrich, 2013d).

Easy-to-use, fluid and adaptable interfaces within a pleasing comfortable contextual surrounding enhances the intuitive user experience and interaction on various levels of conscious and subconscious stimulation. For example; painters use brushes, pastels, paint, framed canvas and many other tools to make abstract representations of their inner and outer experiences to create a window to their world. The same goes for master-chefs who create rich experiences in culinary delights and achieve high levels of creativity in food preparation. The environments these human experts work in are complete and abundant laboratories dedicated to their work, equipped with a wide selection in tools and surrounded by a great variety in raw materials and supplies. The principal idea behind this phenomenon is that context and location (i.e. physical, tangible, visual, audible, olfactory) is crucial to understanding and learning. Digital tools often do not have these intrinsic qualities of the earlier examples, let alone offer an enticing environment to create a rich experience. The creation of virtual representations are in principle so eluding and convincing that, to paraphrase Lanier (2010), designers become prone to rather changing themselves in order to make the computer appear to work better, instead of demanding that the computer be changed to become more useful. McCullough (1998) once wrote that computers now mediate enough activities to suggest that computing's pre-eminence and visibility is somehow related. Still it is hard to believe that in a few decades we allowed so much reductionism, simplification and devaluation of the physical and visual skillsets of humans by allowing computers so much autonomy. On the other hand the seemingly endless possibilities that digital technology has to offer awakens a healthy curiosity to find new meaning, new frontiers and invent new techniques to continue a quest for empathic computational assistants.

Figure 63. Human capacity to externalize meta-cognitive abilities

5.2.2 Intuition and Thinking Processes in HCI

Intuition plays several roles in the product creation process (PCP) and product engineering process (PEP). Intuition in the beginning of a PCP or PEP functions as an inspirational process. It is the search for forethoughts within the user (the subject) and for objects outside of the user (in the world) that can be connected to the design problem. Objects should not be understood as artefacts only but also as thoughts of others. The more uncommon connections laid in this process are, the more creative they will become, to the extent that they are no longer understandable for other subjects. Intuition during the design process enables the user to have a holistic view of the design problem, the information gathered and the ideas created. Kahneman (2011) distinguishes two thought processes or two modes of thinking, which he calls system one and system two. System 1 is commonly called the intuitive system and System 2 the rational system. Both systems process different information and process it in different ways. This leads to postulate that it might be possible to connect this theorem to actual system architecture as illustrated in diagram Figure 64 (Wendrich, 2010b), (Wendrich, 2011b), (Wendrich, 2012a).

Figure 64. Hybrid design processing affords two modes of thinking

The intuitive system is characterized by the following keywords: fast, immediate/automatic, slow learning, effortless, and associative. The rational system is characterized by the keywords slow, controlled, flexible, effortful, rule governed. Usually, when a user is in flow, working under pressure and in concentration, a sudden insight is acquired by the user. Kahneman (2011) stated that, '...Flow neatly separates the two forms of effort: concentration on the task and the deliberate control of attention.' Other users experience an insight when they are not focusing on the design process but on something completely different. Such an insight can best be metaphorically described by seeing the

big picture or all pieces of the puzzle come together. An insight does not mean that the user is able to rationally explain “the big picture”. User intuition could be supported and triggered by presenting him or her with objects (e.g. artefacts and thoughts) randomly or in line with objects from similar projects. This is done to evoke the inspirational process; to facilitate the creation of (uncommon) connections. The intuition of the user could be supported by not only presenting objects to him, but also in advance create connections between objects, for example by presenting them at the same time. Furthermore, the user intuition could be evoked to present an overview of all the gathered information and created ideas. As stated before, some designers get an insight when in flow, others while not focusing on the task; taking a break (i.e. reflection, incubation, contemplation). Therefore to trigger an insight we could simply create this to provide a break(s) during processing. For a quite a lot of users the knowledge gained by an insight is true and real, however, they have difficulties to rationalize the insight. Rationalizing the insight is needed to communicate the knowledge with others and make it plausible for them. An opportunity would be a system that supports the rationalization of the designers insight (Verduijn, 2012).

5.2.3 Tacit and Explicit Knowledge

What shapes our lives and natures is not simply the content of our conscious mind, but in much greater degree that of our unconscious. Between the two is a sieve (seam), and above is the consciousness, only the coarse (raw) material is kept back; the sand for the mortar of life falls into the depths of it; above remains only the chaff, the good flour for the bread of life collects, down there in the unconscious (Groddeck, 1923).

Polanyi (1966) claimed the fact, by reconsidering human knowledge, that we can know more than we can tell. When we touch something with our hands or with a tool our awareness of the impact is transformed into a sense of what thing or object we are exploring. An interpretative effort transposes meaningless feelings into meaningful ones. According to Collins (2010) this is the semantic aspect of tacit knowing. The interface ‘seam’ in a hybrid design tool is very important, here lies the threshold or uncanny valley where the human user makes contact, mediates and interacts with a computer. The user interface should communicate to be intuitive at the same time be calm and comfortable to operate and interact with. In order for our interface to appear ‘intuitive’ for our target audience, we will need to both assume a relatively low prior knowledge of the user and aim to reduce the required knowledge to complete a given task as well. As such we need to take a look at the lowest common denominator in terms of prior knowledge and the required level of knowledge a user needs to have to complete a given task with our interface. The gap between the knowledge a user already has and the knowledge a user requires to complete a given task is our focus in intuitive design as shown in Figure 65 (Spool, 2005).

Figure 65. The Knowledge Gap in human computer interface design

In other words, we set out to design an interface that will bridge this gap as easy as possible. Conversely, an interface may appear intuitive if the gap is small or nonexistent between the knowledge a user already possesses and the required level of knowledge a user needs to have to complete a given task. According to Spool (2005), if there is indeed a gap in knowledge levels, an intuitive design will be a design that will help the user bridge this gap subconsciously. In order to achieve this, we will rely heavily on associations and metaphors a common user is already familiar with in real life. At the same time we acknowledge and recognize the aspects of uncontrollable bias, uncertainty, approximation and unpredictability in real and synthetic environments.

5.3 Hybrid Design Environments, Multi-modality and Tool Development

In this section we present hybrid design environments and tools that were created as part of this research and exploration. We use an agile computing and holistic design approach to hardware and software development. Fundamental is to use commercial-off-the-shelf (COTS) components for hardware and software to reduce cost, facilitate availability and significant savings in procurement and maintenance. We combine these components with custom-made parts and other electronic devices. The real-world interaction metaphor we use for both systems in terms of hardware design and construction is the 'workbench' illustrated in Figure 66 (left) (Stokes, 1829).

Figure 66. *Workbench metaphor (left) and user-in-the-loop tool architecture (right)*

Workbenches were invented and made to support physical and tool activity and to facilitate the work process and task flow. The workbench approach fills the void between mental and physical interaction. We use this metaphor to stimulate the 'barrier' between mental and physical interaction. The stand-up posture is a dynamic trigger to immerse in physical activity and extends the feeling of immersion, motivation and commitment to externalize creative thinking processes. The prototypes that we built for testing and experimentation consist all out of a workbench including a sensorial space and equipped with computational and vision systems (See [Appendix E](#)). The first tool that we created in 2009 was based on a stereo-vision camera system for high-speed tracking of objects or artefacts. The virtual simulations were generated real-time and visualized as polygon-mesh representations on screen. The computational-vision system made a pre-determined timed snapshot of the bi-manual iterative manipulations that were generated by the user (sensorial space) with tangible materials and artefacts.

The instances were listed in a timeline on the right side of the user-interface (monitor). The multi-touch user-interface allowed for selecting, manipulation and morphing the singular captured iterations. It was also possible to merge them with other instances to generate combinations, adaptations and optimize the desired shape or form. The next process-step was to add raw functional elements from a parts-library to the morphed shape(s) to facilitate design and engineering synthesis. The intermediate results of a design interaction process with this system were converted to a stereo-lithography file format to facilitate 3-D AM printing. In short the tool architecture functions as a user-in-the-loop system as illustrated in Figure 64 and 66 (right). The development of this first prototype created a number of interesting possibilities and apparent fallacies in limits of state-of-the-art technology. The real-time computing and visualization of three-dimensional generated objects in 3-D space seemed very difficult on standard computer systems and standard vision-systems. Noteworthy was the relative slow processor-speed of the computers and video-cards in those years. It triggered renewed investigation and exploration towards other avenues and possible tool solutions that could be made with state-of-the-art COTS components on standard equipment. In the following sub-sections we will discuss the various tools and systems that we designed and created.

5.3.1 The Raw Shaping Form Finding Machine (RSFF)

The principal idea to place the user-in-the-loop is to let the user have full control over the system, explore the intuitive interface freely and untethered to accommodate the creative process as shown in Figure 67.

Figure 67. User interaction and hybrid design tool system

In this setup the monitor acts as a proscenium to a virtual reality (McCullough, 1996). The user interaction takes place in a metaphorical 'sensorial space', in which manipulation and transformation of malleable material and/or other plausible materials take place. The user can decide at any moment during or after processing to reiterate or reconfigure the iterative content by blending and morphing the individual virtual instances to create new virtual models or objects. Optimization and redistribution of forms and reshaping parts or whole bodies is afforded by the multi-touch surface. The user interaction is either based on intuitive notions starting from scratch and shaping tangible materials to externalize a low-fidelity model or e.g. Voronoi structure (tessellation) to visualize a conceptual idea or construct. The system represents a real-time interpretation of the rough modeled shape, e.g. a wireframe or surface-model, in many cases a low-fidelity model is more important than an accurate model.

The user feels semi-immersed and interaction is easy and fluid internal representations in the users mind (e.g. ideas, fuzzy notions, imagination) are externalized and become visible and available to others to be discussed, shared and communicated. The product creation processing session can be saved and stored in the data repository for future reference or distributed for further design engineering processing, optimization, adaptation, and/or being developed into concepts and prototypes. Color and texture can be added as additional design and form elements to create formal and informative prototypes. Figure 68 illustrates the interface showing iterative instances and morphing of virtual simulated models to 3-D AM models.

Figure 68. *Tangible modelling, virtual modelling, interface visualization and iterative process steps*

5.3.2 The RSFF Machine equipped with Kinect

The system in Figure 69 has been developed using COTS-components hardware; a normal desktop computer (3.2 GHz quad-core with an NVIDIA 9600GT video card) running Microsoft Windows 7 and a Microsoft Kinect is being used to capture both visual and 3-D information, acting as video camera and depth measurement device. The software makes use of various opensource libraries; the GUI system is implemented with Qt (qt), the 3-D view is based on OpenSceneGraph (osg), and OpenNI (oni) is used to acquire the data generated by the Kinect.

Follow link for video on tool: <https://vimeo.com/43850666>

Figure 69. *Tangible modelling with hybrid design tool and Kinect*

These subsystems are integrated in a custom framework that allows for library encapsulation, parallel task execution and broadcast-style component communication. When in live-viewing mode, the program continuously updates a 3-D model with newly acquired data from the Kinect. Several interpretations of the data can be made, and by default the model is updated with depth measurements only, without any specific kind of coloring. The data flow is illustrated in Figure 70.

Figure 70. *Tangible modelling with hybrid tool and Kinect*

The current setup allows for real-time capturing of 640x480 images with depth measurements for each pixel. The accuracy of the system varies depending on the distance to the depth sensor, no exact measurements are taken as of yet. The reason is that an exact match is improbable, so the algorithm makes use of nearest hamming distance matches. Searching the entire image is an extremely lengthy process, and can be avoided by making use of epipolar alignment - when the cameras are positioned close to parallel to each other their images can be analyzed to find horizontal equivalent lines, which restrict the search space of the stereo matching algorithm from the entire image to a single line of the other image.

5.3.3 The Loosely Fitted Design Synthesizer (LFDS)

The second system is loosely based on the first prototype, however quite different in interaction and representational qualities. The application software was written anew and somewhat different in interaction from the first system. In this tool setup shown in Figure 71, we use one high-definition

video camera to capture real-time images from interaction processing. The interaction controlled by the user pushing a red button or foot pedal (in case of bi-manual interaction) to capture iterations. The virtual instances shown in are listed in sequence of capturing and visualized real-time on screen. The virtual instances being captured by the user are automatically stacked and blended to create a mash-up of digital imagery. Depending on light conditions, stacks could add up between 20 to 25 layered instances. This preconceived darkening effect nudges the user to start a new iterative sequence flow, the idea is to iterate galore and manifest as much iterations as possible illustrated in Figure 72. A special adapted user interface (wireless numpad) affords the user to un-stack the iterative stack(s) and sort, select and structure the virtual visualizations to their choice. Any individual instance or series of instances can be manipulated and transformed to become new iterative representations. The user can tag stacks or instances and make annotations for review, synthesis and decision-making. A special review mode allows for sort, stack and select either loosely fitted or matrix structured. The complete interaction process and generated data can be stored and saved in the data repository in separate process files for sharing or track-back. The user-interface has a setting to export the complete iteration sequences as a compressed stop-motion movie.

Figure 71. The LFDS setup, process flowchart and numpad interface (bottom left)

The hybrid design process flow diagram in Figure 73 links the tool with the dual mode of thinking described as Representation (System I) and Analysis/Synthesis (System II). The user interaction input and captured content generates representation sequences and data flows in the system. The output can be re-used directly by the user to re-iterate intermediate content. If substantial iterations are captured and stored the user can choose to review, select and make decisions on what to keep as possible processing results. In Figure 74 the multi-modalities in the hybrid design environment are illustrated as a Fuzzy-Mode (System 1) and Logic Mode (System 2). The system architecture consists of an Asus Motherboard P8P67-M CPU LGA155 with an Intel Processor i5 Quad Core and NVIDIA GeForce GT250 2GB SDDR3 64Bit Graphic Controller. The system runs Microsoft Windows OS7 with a 20 Dell

Monitor, and Logitech HD Pro webcam C910 attached. The Logitech N305 wireless numpad and button/foot-pedal user-interfaces are customized to afford input. The software is programmed with Open Source platforms; for the interface, application, encoding and system layer we use haXe, Neko, and Screenweaver. The haXe code is compiled to Flash files for the graphical environment, the save files are in XML format. The movie file is saved as MPEG (MP4 / h2.64).

Figure 72. *The LFDS interaction, representation and typical iteration flow*

Follow link for video on tool: <https://vimeo.com/20834839>

Figure 73. The LFDS system flowchart showing representation and synthesis

Figure 74. Two diagrams illustrating dual-mode system integration in hybrid design tool

5.4 Experiments and Case-Studies with Hybrid Design Tools (HDT)

In this section we present integrated PCP and PEP experiments with the LFDS hybrid design tools in the Education⁸ domain (Wendrich, 2012). The two experiments described here address presentation and representation in a hybrid design tool environment (HDTE) that includes traditional and computational design tools as shown in Figure 75. The experiments attempted to test creative problem-solving, sequencing of iteration process, performance success and solution time. We included master design engineering students in our design experiments. Participants in Experiment I and II solved design problems using prescribed constraints in the form of analogy and metaphors. In design by analogical reasoning and concept blending, the designer uses his/her own intuition, experience and knowledge and applies them to the new problem. The design metaphors are real-world artefacts (i.e. raw functional elements) to be included and become part of the solution space. All the interaction was video recorded with consent of the participants. The video footage was analyzed using Video Interaction Analysis (VIA) as developed by Jordan and Henderson (1995) to make qualitative investigations and evaluations on human activities, such as talk, nonverbal interaction, and the use of artefacts and technologies, identifying routine practices and problems and the resources for their solutions. Research questions:

- How do design engineering students explore the design space during the initial ideation phase of design?
- How do they use product features and constraints to generate potential design solutions?
- How will the use of a HDTE support the design process to generate and transform ideas?
- How will the use of a hybrid design environment support flow in design processing?

Figure 75. Visual impression of hybrid design tool environment

⁸ 'He must be freely enlightened to self.' This is the crux of the educational system you find so appalling. Not to teach what to desire. To teach how to be free. To teach how to make knowledgeable choices about pleasure and delay and the kid's overall down-the-road maximal interests.' - David Foster Wallace (1962-2008) *Infinite Jest*

5.4.1 Experiment I

This design task was executed by individual participants. The participants were asked to create and design new product concepts using the HDTE as illustrated in Figure 75. The design experiment was conducted with seven participants. A total of seven concept design tasks were executed and seven individual feedback forms were handed in. They all had no former training or experience with the HDTE. The allowed time constraint was thirty minutes per participant. In some cases we allowed more time for unexpected downtime, questions or rupture in the system. Virtual iterations (instances) made by the participant were captured by the user and stored in the data repository of the computational hybrid design tool. Tangible iterations and representations were saved and documented after each session. The participant was shown an analogical image, as described by Gero and Maher (1992), of a whisk and handed two predetermined metaphorical artefacts, demonstrated by Goldschmidt (2001) as design constraints to facilitate and enhance the design task as shown in Figure 76. The task to perform was: to design an electrical mixer from scratch. Overall, intention, performance and motivation seemed very high during interaction and processing. Creativity was evaluated on the basis of the generated design concepts, number of iterations, interaction time, total tangible and virtual models, task success, and level of completion. In Figure 77 we show snapshots of the design processing sequences, the back and forth between design table and design tool during the iteration and ideation process is clearly visible. Metrics of the seven individual product creation processing's (PCP) are shown in Table 2, at the end of each task we collected the data and at the end of the entire session. Some of the tangible and virtual results will be shown in Figure 78 to visualize the variations and serendipity in solutions and presentations. The results are evaluated based on the amount of satisfaction and ease of use that the participants communicated in their feedback after the sessions.

Figure 76. Diagram individual setup and metaphorical artefacts

Figure 78. Analysis and features of the individual design process

5.4.2 User Feedback Experiment I

We gathered written feedback from all seven users after the sessions terminated, the users expressed and evaluated their experience, interaction, ideation process, and performance. They all liked the speed and fast iteration combined with the virtual visualization and representation on the display. The use of physical constraints was considered very helpful and informative by five users. They liked the direct tangible information on weight, proportion, and scale to use in relation to the design task. The visual analogy was neither effective nor stated helpful, this could indicate that the product design task (mixer) already has associative meaning and context known to the participants. Some indicated that the hybrid tool constitute a rupture in user behaviour and the user had to first disconnect themselves from earlier learned methods and techniques. Most users liked the real-time capturing of iterative content and some indicated that the merge of physical (i.e. hands) and virtual (i.e. prototype) were very useful. Positioning and placing parts in different angles gave clues and information about location, assembly, aesthetics, and user functions. Also the use of less material for physical prototyping in conjunction with the constraints was indicated as a gain. Three users indicated that "... the buildup of the design by layers offered creative freedom, makes you think about progression of the next iterative step(-s) and, the possibility to build a product-architecture." Some drawbacks of the hybrid system mentioned were the user-interface (UI) (numpad) to some this should be a multi-touch and interactive on the screen. Some indicated the UI initially hard to understand in functionality. One user, as shown in Figure 77 (sequence 6 to 10), indicated that although she really enjoyed working with the tool she could not complete the design task because of frustration and loss on how to use the functions of the user- interface (numpad). P1 indicated: "I lost my way! Did I do something wrong?" Experimenter: "No, there is nothing you can do wrong." P1: "I tried everything." Experimenter: "What did you try to do?" P1: "Copy the cord into it,...but it doesn't work!?"

5.4.3 Experiment II

In this experiment the participants were asked to perform a collaborative design task using the hybrid design environment illustrated in Figure 75.

Figure 79. Collocated experiment setup and metaphorical artefacts

The design experiment was conducted with four participants, randomly paired in two groups. A total of two concept design tasks were executed and four individual feedback forms were handed in. They all had no former training or experience with the HDTE. The allowed time constraint was forty-five minutes per group. In some cases we allowed more time for unexpected downtime, questions or rupture in the system. The sessions were video recorded with consent of the participants. Iterations made by the participants were captured by the user and stored in the computational hybrid design tool. The participants were briefed on the design task by the experimenter. They were shown an analogical image of a pad / tablet and five metaphorical artefacts were handed as predetermined parametric and physical constraints during the PCP shown in Figure 79. The group interaction and dynamic were very lively and the overall intention and motivation was very high during the sessions. Figure 80 shows an impression of the group interaction during processing and ideation. Metrics of the two collaborative PCPs are shown in Table 3.

Figure 80. *Collocated user interaction, case studies G1 and G2*

At the end of each task we collected the data and at the end of the entire session. The results are evaluated based on the amount of satisfaction, comfort and ease of use that the participants communicated in their feedback after the sessions. In Figure 81 we present some results of the collaborative iterative PCP and show the variety in tangible materials, representations and virtual iterations made during the sessions. The low-fidelity models are very frugal and simple but convey the intention and make the ideas of the designers clear in their approach to the problem-definition. The negotiation and reflection-in-action as demonstrated by Schön (1992) during the collocated experiments showed the effectiveness and efficiency of tangible representation, gestures, and speech to communicate thoughts and express ideas. Conscious deliberation is a goal driven process.

Table 3. Analysis and features of the collocated collaborative product creation process (PCP)

Experiment II – PCP collaborative		
Participant	G1	G2
Number of iterations	46	93
Interaction time in minutes	59	58
Average iterations/minute	0.8	1.6
Number of virtual models	5	9
Number of physical models	7	16
Task success in %	60	80
Completion in %	70	90
Likert scale* measures per group		
Satisfaction user interface (UI)	1	2
Ease of use	1	2
Satisfaction PCP	L	N
Satisfaction collaborative effort	L	N
* 1 = no problem L = like		
2 = minor problem N = neutral		
3 = major problem U = unlike		
4 = failed		
Total of 4 participants (2 groups) – 139 iterations – 2.0 hours of PCP interaction time

Figure 81. Physical and virtual intermediate models from Expt. 2

5.4.4 User Feedback Experiment II

In the written feedback we gathered from the four participants we noticed some differences in experience. One group indicated that the collocated process was very pleasant and that they gained

from mixing ideas. The other group were divided one participant wrote that the collaboration went great, the other had doubts about his own performance and thought that the collaborative aspect had a direct influence on his own ideas and thinking. It deviated too much from the target of his own path (ibid.) Working in the hybrid design environment was considered by both groups as a positive experience and enjoyable. They indicated that the manipulation of objects and artefacts was easy with two persons collaborating on the same design task. One participant wrote, "through the combination of physical and computational tinkering there seems to be more space for creative ideation. You do not feel limited by the computer, but it allows total freedom of creation which in turn leads to interestingly fascinating results. It is really easy to get real-life models in the computer." Another participant noted, "Every material has constraints and needs a certain kind of processing and thinking. (Advantages and disadvantages were automatically weighed) This is exactly what is so great about this apparatus, keep it that way! (It seems logical and on target)." Notably is the amount of discussion, reflection and deliberation in collaborative interaction, whereby ideas are externalized, manifested and pondered frequently. In such cases the external process stopped to allow internal contemplation, negotiation and imagination. Disadvantages mentioned by two users were navigation and interaction with the numpad, this should be supported with a multi-touch screen instead.

5.5 Preliminary Findings

In the user feedback we noticed an overall appreciation of the hybrid design tool environment. The users all indicated to find the hybrid tool not invasive or obtrusive during interaction, some mentioned the interface being intuitive and comfortable. The supported multi-modality and physical aspects of the HDTE were considered very helpful and stimulating, according to some the complete design process becomes much more interesting once you understand the interface fully. Findings from Experiment I support some of our research questions in exploration and the front-end of a design ideation process. The use of constraints; as described by Norman (2002), 'so that the user feels as if there is only one possible thing to do - the right thing, of course', added favorable to exploit and explore potential design solutions. The generation of and transformation of ideas and abstract notions was clearly visible during the sessions and documented in the data base of the system. We can conclude that the HDTE supports this hypothesis. Most participants expressed that they would have liked to spend more time on the design task and wanted to work in the HDTE again. Furthermore, this suggests that time was consumed much quicker than anticipated and points in the direction of flow. Flow as described by Csikszentmihalyi (1990, 1991) as the merging of actions and awareness-avoiding distractions-forgetting self, time, and surroundings. Experiment II is too small in sampling rate to justify any conclusions at this point in time. However, both experiments foster further investigation and experimentation, the challenge for the future is to map and extend the details of this multidimensional space.

5.6 Conclusion

The adaptability and gradual removal of existing interfaces or devices becomes more and more fluent and congruous. In education and teaching the threshold and learning curves of most CAD programs are rather high or very steep and that in turn creates a significant amount of stall in learning skills, understanding, insight, ideation and creative processing. Creative problem solving is valuable at any stage in the design process, but it is of critical importance in the conceptual design stage. While a significant amount of research has been conducted into ways to improve interface design to assist in producing creative output, it has been noted that commercial CAD tools can lag one or two decades

behind the first demonstration of a new idea in this area (Seguin, 2005 in Robertson et al., 2008). The more time people spend on learning and tinkering with computers, the less time they spend setting goals or applying existing skills (McCullough, 1998). Reflection, incubation and learning are encouraged when technology is supportive and calm, it allows user-control, engagement and foster learning skills while harnessing talent. The right tool support is crucial to the learning experience, simultaneous interaction, individual- and collaborative ideation and processing, ... a tool is a moving entity whose use is initiated and actively guided by a human being, for whom it acts as an extension, towards a specific purpose. Tools remain subject to our intent. We have to ask ourselves are the digital approaches a thread or a blessing to human kind? Do we really gain and profit from virtual reality machines to improve our physical world? The reductionism in hand-eye coordination has already taken place, and will continue to do so if we don't take up the challenge. According to Lanier (2010) virtual reality was built to make this world more creative, expressive, empathic, and interesting. It was not to escape it. We have body awareness and spatial understanding of our bodies independent of the environment. We are aware of the relative position where our e.g. limbs, hands and feet are, thereby perceive and sense our surroundings continuously. We developed skills and coordination of motion and locomotion to do things manually or combined interaction. Technology changes people and computers changes interaction and skillset of people to the extent that we continuously have to lower our standards. Better sensory frameworks, not limited to vision, make for better computing. Better software to orchestrate our skills and senses, and to structure our mental models, makes for more satisfactory work (McCullough, 1996). Every instance of intelligence in a machine is ambiguous (Lanier, 2010). People need an abstract grasp of structural features as the very basis of perception and the beginning of all cognition. Sketches are abstract and can be interpreted in various ways and preferred means of representation and communication (Brereton, 2004). Tangible models can be either abstract or concrete representations and convey variable information and allow for serendipitous interpretation. The combinations of traditional representation techniques are fundamental in creating insight, learning and understanding.

A hybrid combination of these real world skills, techniques, tacit knowledge, intuitive interactions, experiences and virtual reality oscillated in abstract and concrete representation should be well-balanced, natural and harmonized. Jacob et al. (2008) describes this as reality based interaction (RBI) as a unifying concept that ties together a large subset of emerging interaction styles. We have evolved through the decades hand-in-hand with computers and digital worlds, however we still have a long way to go and be skeptical and cautious to really understand and know what is going on. We based our interaction on pre-existing real world knowledge and skills. Jacob et al. (2008) argue that interaction based on the former may reduce the mental effort required to operate a system because users already possess the skills needed. For casual use, this reduction might speed learning. However, in situations involving information overload, time pressure, or stress, this reduction of overhead effort may improve performance. Applying RBI concepts such as naive physics (Hayes, 1978) to an interface design may also encourage improvisation and exploration because users do not need to learn interface-specific skills. In our research experiments and tool testing in real world case studies we observed highly-motivated users having virtually no trouble handling the user-interface while exploring the possibilities of the tool simultaneously manipulating real-world materials, objects and tools to visualize and represent their ideas and abstract notions. The tools offer an empathic and elegant solution for externalization of creativity and ideation wherein the user-in-the-loop feels in control, intuitively manipulation of the interface and objects to trigger inspiration and imagination. Human perception is not a direct consequence of reality but rather an act of imagination (Faraday

in Mlodinow, 2008). Finally, the hybrid approach to integrate existing and new advances in HCI, problem-solving, decision-making, mind-mapping, afford universal cross-domain access in conjunction with multi-disciplinary areas calls for a mere calm, empathic, and, holistic approach in the now and near future. To think about technologies, however, you have to learn to think as if you're already living in the future (Lanier, 2010).

RST Research Timeline

ABSTRACT

In this chapter we present a case study on design interaction and processing incorporating triple tool modalities within an educational context. The methodology and processes applied are directly related to our research and exploration for new design tools, mixed reality, user-interfaces and user experiences based on a holistic framework and learning-by-doing approach in early phase design processing. We deployed three separate collaborative design-task tests based on the same problem definition. We studied the correlation between the ease of tool use, tool performance, tool satisfaction, tool expectations and experience.

Keywords: ideation, design tools, externalization, representation, collaboration, education

CHAPTER 6

Triple Helix Ideation: Comparison of Tools in Early Phase Design Processing: Case Study Education

(This chapter is based on the peer-reviewed paper: "Wendrich, R. E., (2014). Triple Helix Ideation: Comparison of Tools in Early Phase Design Processing. In DS 77: Proceedings of the DESIGN 2014 13th International Design Conference.")

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6.1 Design Methods and Alternatives

In general design methodologies and process models have similarities across disciplines (Birkhofer, 2011), (Gericke and Blessing, 2011) the core of these are common design stages or phases and they propose a stepwise, iterative process. In recent years a wide variety of authors identified and compared these design methodologies and design process models in mechanical engineering, service design, mechatronics and other disciplines, for example (Archer, 1964), (Roth, 1982), (Cross, 1984), (Birkhofer, 2004), (Ogot, 2004), (Pahl and Beitz, 2005), (Howard et al., 2008), (Kim and Meiren, 2010), (Gericke and Blessing, 2011) that created some sort of consolidation on commonalities across disciplines. Of course when reviewed extensively the cross-overs become apparent and show common threads, patterns and themes no doubt. However, the different studies on design methodology are also fragmented and flawed by gaps in understanding, insight in context, and properly defined frameworks. Nonetheless, current and future development of design methodologies are in need of reformation (Birkhofer, 2011) since they are often insufficient, comprehensive, and long-winded (Birkhofer, 2011) that implementation and/or adaptation in industry still is reluctant and partially successful. To keep-up with the fast and rapidly changing world design methodologies should be adapted, developed, and reformed to adhere to the increase and need for multi-disciplinary collaboration in design processing due the rising complexity in design problems (Gericke and Blessing, 2011). The use of computers (CAD) plays a very important, often dominant and crucial role in design processes not only in industry but also in education (Wendrich, 2012a), (Wendrich, 2012b). However, most design methodologies only partially meet and/or favor computer use (Birkhofer, 2011) and could not keep pace with computers. In our research we rely on the interplay between a creative thought and action, based on experience and intuition of the individual designer and a systematic procedure, based on scientific work (Birkhofer, 2011). We propose a more holistic view on design processing and methodologies to benefit and gain from unpredictability, uncertainty and intuition. Prior experience, tacit knowledge, practice and learning-by-doing are fundamental in our interpretation in the world of ideas.

6.1.1 Rawshaping Procedure

Since 2009 we deploy the rawshaping procedure to investigate and explore the fuzzy front end and ideation phase of design processing. The methodology and process applied stems from the research and exploration for new design tools, mixed reality, user-interfaces and user experiences based on a holistic framework and learning-by-doing approach to determine next steps in analysis and synthesis for heuristic shape ideation. In fact there is no apparent 'methodology' that is required to start a rawshaping process, however to fully benefit from the procedural steps it is necessary to create a re-adjustment of mindset and an open approach towards rawshaping ideation. For more data and full account of rawshaping research we refer to its primary documentation (Wendrich, 2010a), (Wendrich, 2014c), (Wendrich, 2016d). Idea finding, creative exploration, possible solution finding, and ignition of search paths are a dominant part in any design and/or engineering process. In most cases the start or kick-off of such a process, especially when some form of mind-storm, idea-burst or creativity is required or needed, requires a lot of effort and energy regardless of experience, expertise or specialism. Play and CAD Game System (CGS) mechanics are an important aspect of the rawshaping process action; through adaption of these standards the process of design iteration becomes much more playful, engaging and rewarding (Kosmadoudi et al., 2013). Thereby introducing

some randomness⁹ in findings and exploring neighbouring solutions preventing to become trapped in a local neighborhood. Furthermore, we recognize a strong metaphorical connection, analogy and cross-over between rawshaping and the Japanese Kansei design and engineering strategy (Levy, 2008). The inclusion of senses (i.e. touch, sight, taste, hearing, and smell), perception (i.e. thermo, noci, equilibrium, proprio) and tacit knowledge (i.e. experience, personality, mood, condition) has a strong foundation in rawshaping as well as in Kansei. Kansei is an advanced function of the brain that can be the source of emotion, inspiration, intuition, pleasure/displeasure, taste, curiosity, aesthetics and creation (Beuttel, 2010).

6.2 Triple Helix Ideation and Experimentation

In the following case-study we show a triple design ideation and representation experiment for an early design activity (fuzzy front end) with three tool environments, i.e. analogue, digital and hybrid for triple helix ideation. We deployed three separate collaborative design-task tests based on the same problem definition in conjunction with three different design tools and set-ups. We studied the correlation between the ease of tool use, tool performance, tool satisfaction, tool expectations and experience. Tool fluency, adoption and adaptation by users are expected to be immediate and congruent, however we contend that this rapid assimilation of the new or innovative technologies (i.e. tools) only happens when users accept the technology (e.g. device, tool, system) (Kaapu et al., 2013). In addition the user acceptance and uptake of technology occurs when the user perceives it as a pleasurable extension on their physical reach.

6.2.1 Test Procedures

The testing took place over two test session dates with 4 paired groups of approximately twenty-five students. The students randomly formed pairs on both dates. The participants in this experiment are considered novice students in design engineering and all are second year Bachelor students in design engineering education in our university. During the second testing date one group of students was considered a placebo group and were not informed or made aware of this because of ethical reasons. Their 'results' did not matter on our testing and therefore is not included in the results and analysis of this experiment. This study shows preliminary findings and are limited in scope.

6.2.2 Group Participants

In the first test session we divided a group of over fifty students (females and males - variance per dates) in two and paired them to form collaborative groups. The A-groups (16 gr. Analogue - 32 part.) only used analogue design tools (e.g. markers, paper, pencils) to execute the design task. The D-groups (11 gr. Digital - 23 part.), used their laptops (e.g. CAD software incl. mouse, tablet, etc.). No access to the Web was allowed during the execution of the design task. In the second test we once again randomly divided the students in two paired groups. The H-groups (19 gr. Hybrid - 38 part.) were to use two hybrid design tools (Wendrich, 2010, 2012) for execution of the design task.

⁹ 'In nature we never repeat the same motion; in captivity (office, gym, commute, sports), life is just repetitive-stress injury. No randomness.' - Nassim Nicholas Taleb (2010)

6.2.3 Design-task, Facilitators and Constraints

The design task was to collaboratively design and ideate a hydrogen car (Fig. 82 left) thereby include the predetermined constraints of functional elements within the possible design solution space. The objective of the design task was to make as much iteration as possible. The time frame allowed was 10 minutes. Groups A and D were handed A4-prints with constraints or download a pdf (Fig. 81 middle). The H-groups used the hybrid tools and 3-D AM printed scale models of the functional element constraints (Fig. 82 right). During sessions we used facilitators for simple instructions to participants.

Figure 82. Hydrogen car framework, 2-D constraints and 3-D constraints

6.2.4 Tools and Setup

The A and D were separated in the lecture room (Fig. 83 top). The A's were required to use analogue tools and papers, D's were to use their laptop with tools of their choice. For the H's the setup included two hybrid machines with one facilitator each for initial instructions and brief assistance (Fig. 83 bottom).

Figure 83. Triple helix ideation setup

6.2.5 Analogue and Digital environments

Figure 84 shows the analogue collaborative interaction and representation, face-to-face communication embedded with sketch, draw and idea creation. Use collective processing to find suitable and possible solutions in a fast, iterative, and interactive way of working. Sharing knowledge and ideas this way feels natural, intuitive and real. However, the need for adequate drawing and sketching skills to convey your thoughts and ideas are also part of a successful performance and communication. Most sketches and/or drawings were a mixture of two- and three-dimensional representations of possible embodiments of car-like designs. Most of the concepts contained the constraints such as motor, fuel-tank, and wheels in different assembly configurations. Many drawings showed annotations depicting the key features, requirements and relevant information about the proposed ideas behind the concepts. This kind of fine-tuning shows a certain skill-based level, depending upon the continuous updating of the sensorimotor schemata to the temporal and spatial features of the task environment, the speed-accuracy trade-off (Rasmussen, 1998).

Figure 84. *Analogue tabletop ideation*

During digital ideation we observed the use of a variety in user interfaces (i.e. mouse, keyboard, tablet, fingers) as input devices and diversity in CAD software (tool) usage (Fig. 85). We noticed the use of Adobe Photoshop (4 part.), MS Paint (16 part.), SketchBook (tablet) (2 part.), Sculptiris 3-D (1 part.) and Adobe Illustrator (1 part.). Surprisingly relative simple programs were used to design and 'sketch' ideas, most of these programs are primarily used for two-dimensional graphic representation and visualization. Strikingly, when we asked the participants after the test which program they had used the most; it showed that 70% worked in MS Paint. The other 30% used Adobe or SketchBook. The reason why is probably on the rule-based level, the performance depends on the empirical correlation of cues with successful acts. Humans typically seek the path of least effort. Therefore, it can be expected that no more cues will be used for discrimination among the perceived alternatives for action in the particular situation (Rasmussen, 1998). The drawings made with the digital devices and tools (laptops) showed a large variety in quality, depth, scale, skills and outcome. All concepts were two-dimensional elevations of possible solutions, most of them were very frugale and simple line drawings. In a few cases we found a combination between embodiment and assembly configurations.

Figure 85. *Digital laptop ideation*

6.2.6 Hybrid Design Tool Environment (HDTE)

The second test with the hybrid design tools showed a back and forth between material representation and playful activity between the participants (Fig. 86). The three-dimensional constraints were used to create virtual models in conjunction with sketches, drawings and other material artefacts. The negotiations between abstract and material representations are instrument to thinking-in-action, learning-by-doing, exploration, reflection-on-action, and discovery (Schön, 1984), (Brereton, 2004), (Wendrich, 2009).

Figure 86. *Hybrid workbench ideation*

6.3 Performance and Results

The following results from the triple helix ideation experiment show variety, diversity and serendipity in representation of ideas on paper, screen or hybrid mixed reality.

6.3.1 Analogue and Digital Results

In Figure 87 and 88 we present a concise selection from analogue and digital ideation and iteration processing. The application and adaptation of the constraints are clearly visible as an intrinsic part of the representations. Some indicate the parts as symbols (letters), others as drawing or pasted graphic from the pdf. Notice that the digital sketch visualizations predominantly show side view elevations.

Figure 87. Analogue sketches with 2-D constraints

Figure 88. Digital sketches with 2-D constraints

6.3.2 Hybrid Results

Figure 89 presents a random selection of merged representations from user interaction. The visualizations clearly show the functional element constraints and iterative solutions. The visualization shows various viewing angles and elevations. Representation in two-dimensional space seems like a common denominator in visualization and an easy-way-out. Although the hybrid design tool affords

both two- and three dimensional iteration, the novice users probably feel more comfortable and at ease to work on a horizontal (tabletop/workbench) plane instead of using the spatial capabilities of the tool.

Figure 89. Hybrid sketches with 3-D constraints

The facilitator specifically did not mention this to the novice users to observe how they would interpret and use the tool from the onset. Remarkably, none of the H-groups started working in three-dimensions right away; they focused more on fulfilling the design task than on exploring the possibilities and features of the tool. Even the three-dimensional constraints were not seen as essential or prospective triggers (as more or less expected), the artefacts were used as 2-D objects within their respective solutions.

6.3.3 Hybrid Results with Facilitator Nudge

After 5 minutes the facilitator stepped in to give some simple instructions (nudge) and pointers to disrupt the process and make the participants aware of the multi-dimensional iteration space. Some results of these next iterative steps are shown in Figure 90. Nudge is an essential element to create direct awareness and stimulate attention to the task-artefact cycle, as described by Thaler and Sunstein (2008). This nudging could be facilitated by a facilitator or through system indicators during the design process procedures.

Figure 90. 3-D Hybrid sketches with 3-D constraints after facilitator nudging

6.3.4 Reflection and Feedback

All the participating groups were asked to fill in questionnaires made available online directly after the test sessions. We used SurveyMonkey (SurveyMonkey, 2009) to acquire responses and compile all the data from the questionnaires for analysis and evaluation ([Appendix F](#)). We issued three different questionnaires for each of the three test set-ups (Tables 4 - 6). The A-groups had 9 questions, the D-groups and H-groups both had 10 questions. In addition to survey, we captured all the interaction and testing on video for further analysis and evaluation. In this paper we only present the data from the three surveys as preliminary findings and results. The questions about the tools ranged from user experience; user interaction (input); ease of use; user productivity; user satisfaction; user exploration; user performance; user progression; user expectation; and user success (output). We used the Likert Scale method to investigate, measure and survey the various tool modalities, interactions and representations in relation with measuring the user experience (UX), engagement (UE) and performance (UP) (Tullis and Albert, 2010).

6.4 Findings Survey

The data from the survey showed clear evidence of how tools influence the behaviour, ideation, and interaction, performance and productivity of users during design processing.

6.4.1 Analogue and Digital Q&A

The following survey results show the percentages and ratings of the questions with regards to the analogue test (Table 4) and the digital test (Table 5). The first question in Analogue was: "Did you have previous experience with traditional design tools?" Response was: 100% Yes and 0% No.

Table 4. CDI Analogue questions 2 - 9 (from left to right, top to bottom)

In the diagrams we can see the various key performance indicators (KPI) of working with traditional analogue design tools. The first question was, as one could expect, a pretty obvious answer to a rhetoric question. Everyone has worked or experienced working with pencils, markers and paper, in effect with traditional design tools. Most users show fluency and possess adequate skills to design and make representations with these kind of design tools. Even the most less-skilled and/or experienced users seem to be able to create and make presentable sketches and drawings based on their ideas, thoughts or fuzzy notions, in such they have no difficulties with tangible tools. Over 40 % agreed or very much agreed that their performance and productivity were satisfactory. Most users (strongly) agreed on the overall satisfaction and fluency of traditional design tools, while at the same time the tools meet their expectations. The score on tool expectation was very high, as well as the overall score on the success rate of their output. The question suggested that the output was creative, however

this cannot be validated or rated as such. The notion that the participant thought of himself as 'being creative' in execution of the design task (externalization) shows how people in general think about themselves once they immerse themselves in sketching and/or drawing representation.

Table 5. CDI Digital questions 1 - 10 (from left to right, top to bottom)

In the above diagrams we present the various key performance indicators (KPI) of working with digital design tools (DDT). Most users (80%) noted that they had previous experience with DDT's, although their level of experience was intermediate (65%). This shows the apparent meager skill-sets, low self-confidence and the existing knowledge-gap of the users. Furthermore, it could indicate signs of insecurity and lesser control on DDT's. This assumption show somewhat true in questions number 3 to 6. Most users indicated to disagree with the ease-of-use, speed of recovery, pleasurable of the interface and performance productivity speed. The latter showed a dispersed graph of agreeable and disagreeable answers, indicating the mediocre, uncertain and faltering user-interaction (IxD) and user-experience of DDT's. The overall satisfaction with the DDT's seemed very low, as well as the quick and easy exploration of software features clearly showed difficulties by most users. These findings correlate with the performance indicators in question number 9, whereby the users indicated that DDT's are not straightforward in performing design tasks. On average the DDT's did not meet the users' expectation that much, most scores were between 10 - 15 % from the majority of users.

6.4.2 Hybrid Q&A

The following survey results show the percentages and ratings of the questions with regards to the hybrid test (Table 6).

Table 6. CDI Hybrid questions 1 - 10 (from left to right, top to bottom)

In the above diagrams we can see the various key performance indicators (KPI) of working with hybrid design tools (HDT). Ninety-five percent indicated that they never had used or experienced a HDT before. Although they indicated a mere 73% of experience level with computational tools, 15% stated to be novel users and some (approximately 12%) felt like expert users. The HDT's is easy to use (high scores overall) and most users stated that they could easily and quickly recover when they made a 'mistake'. Almost fifty percent indicated that the user interface (IF) was pleasant, whereby almost 30% somewhat agreed on the pleasurable IF. Forty percent stated that their performance and productivity was good, another 45% indicated fair progressions during the execution of the design task. The satisfaction and performance with the HDT's were good showing high scores with most of the users. The exploration of the tool features was indicated from fair to easy by 85% of the users. In terms of tool expectations 57% indicated ranging from very good to excellent, 23% stated the expectancy as good, whereby 20% found the expectation of the tool was fair. Overall the HDT's showed promise and the majority of users were pleasantly surprised, motivated and engaged during the execution of the design task.

6.5 Conclusions

We presented a case-study on collaborative design ideation. The participants had to iteratively design and ideate a hydrogen car including predetermined constraints. Design task time was ten minutes per test. This test required focus, attention and creative inspiration from both participants collectively. Playful suggestions in sketch, low-resolution models and show-and-tell enforced the common ideas and creation of possible solutions within the design space. The representations of ideas on paper, screen or hybrid mixed reality show a wide variety and differences in solutions and possibilities. The majority of solutions were based two-dimensional elevations and representations. Only the analogue (A) sessions showed a rich mix of two- and three dimensional visualization and iteration. Perhaps the analogue domain intuitively feels more comfortable to represent in multiple

dimensions and probably affords being less restricted in externalization, scalability and presentation. The participants working on laptops and using software tools mostly used illustration based programs to create and make representations. After analysis, feedback and evaluation of the uploaded digital (D) content we found that 90% of the participants used MS Paint. Only a few participants used other graphical programs to convey their ideas. We noticed a strong focus and emphasis on side elevation views in their overall solutions. The initial hybrid tool (H) outcome showed various angles and elevation views, however congruent to the digital these were also mostly two-dimensionally structured and designed. There seems to be a strong tendency to ideate and create on a two-dimensional plane when asked to digitally design and solve a design problem. Even with a hybrid tool, however intuitive and multi-dimensional, the participants rather work on an X-Y plane to make their iterations. This may-be caused and influenced by earlier analogue-digital experiences, common approaches, routines or initial blindness (*blindspots*) to potential possibilities when confronted with a new design tool. We showed that with some nudges from the facilitators, users/participants had the ability, vision and flexibility to enhance their performance and started to create three-dimensional models with the hybrid tools. In our preliminary findings we conclude that analogue tools are still very fast, easy-to-use, flexible and comfortable. There seems to be fluid and confluent transformation sequencing between two- and three dimensional processing. The digital domain remarkably showed evidence of restrictiveness, cumbersome and latent interfaces in working fast and fluid during creative interaction.

The overall results showed merely stacked structures of functional elements in conjunction with a car-like shape ideation. We were amazed by the fact that so many participants used MS Paint to create and iterate ideas. This possibly shows some evidence on how the current (solid) state-of-the-art in design tools, interaction and usability are perceived and used by novice designers. Although the participants were free to use any software program, we realize that there might be some bias in these findings. The interaction and representation with the hybrid tools showed initially more of the same sort of solutions as with digital tools. However, after brief instructions (nudging) of the facilitators the participants showed lively and vivid interaction with the tools. The generated content indicated progressions and transformations in three-dimensions whereby the 3-D constraints formed the core of the hydrogen vehicle and shape aspects indicated the embodiment. Noteworthy are the variety in assemblies and constructive inventiveness of the solutions. We observed playful aspects, motivation, focus and creative tinkering in the participants during the last part of the design sessions with the hybrid tools. This educational case-study is part of our on-going research in hybrid design tools, ecosystems and design environments.

RST Research Timeline

ABSTRACT

Chapter 7 describes the development and evaluation of mixed reality tools for the early stages of design and engineering processing. Externalization of ideal and real scenes, scripts, or frames are threads that stir the imaginative exploration of the mind to ideate, formulate, and represent ideas, fuzzy thoughts, notions, and/or dreams. The body in the mind, embodied imagination is more important than knowledge. Current computational tools and CAD systems are not equipped or fully adapted in the ability to intuitively convey creative thoughts, closely enact or connect with users in an effective, affective, or empathic way. Man-machine interactions are often tethered, encumbered by e.g. stupefying modalities, hidden functionalities, constraint interface designs and preprogrammed interaction routes. Design games, mixed reality, 'new' media, and playful tools have been suggested as ways to support and enhance individual and collaborative ideation and concept design by improving communication, performance, and generation. Gamification seems to be successful especially in framing and/or blending common ground for collaborative design and co-creation processes. Playing games with cross-disciplinary design teams and future users in conjunction with tools to create stories, narratives, role-play and visual representations can be used as abstract ideation and design material in an open-ended design process. In this paper we discuss mixed reality tools based on a holistic user in-the-loop approach within playful stochastic environments. We present preliminary findings and studies from experimentation with robust tools, prototypes, and interfaces based on our empirical research and work in progress.

Categories and Subject Descriptors (according to ACM CCS): B.6.3 (Design Aids): Automatic Synthesis - Simulation

CHAPTER 7

Mixed Reality Tools for Playful Representation of Ideation, Conceptual Blending and Pastiche* in Design and Engineering

(This chapter is based on the peer-reviewed paper: “Wendrich, R. E. (2014, August). Mixed Reality Tools for Playful Representation of Ideation, Conceptual Blending and Pastiche in Design and Engineering. In ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V01B-T02A033-V01BT02A033). American Society of Mechanical Engineers.”)

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* Pastiche is to imitate, to mixture, to blend, to parody the style of another work, designer, artist or period.

'Physics has found no straight lines - has found only waves - physics has found no solids - only high frequency event fields. The Universe is not conforming to a three-dimensional perpendicular-parallel frame of reference. The universe of physical energy is always divergently expanding (radiantly) or convergently contracting (gravitationally).'

- Richard Buckminster Fuller (1969)

The coexistence of the new and the old, the digital and the analogue, is a fait accompli: the question remaining whether this shift is one of degree or, more radically, of kind? (Jenkins, 2006). In studies and research on design and engineering, the questions we face: is ours a transitional (hybrid) time or are we facing a totally new world? (Hutcheon, 2012). Prensky (2001) already stated that a really big discontinuity has taken place. One might even call it a "singularity"- an event that changes things so fundamentally, that there is absolutely no going back. This so-called "singularity" is the arrival and rapid dissemination of digital technology. For the facilitation, communication and spread of information the digital pandemonium has been great and continues to expand. The speed of Internet, cloud computing, web technologies and virtualization progressed speedily and emergent towards utility computing. However, still we are left with a lot of gaps, due to this hyper-revolution of digital technology, mainly in the interface-of-things, user-experience (UX), and human-computer interaction (HCI). Most research done in this field focuses on the emergence of 3-D computational design and the domain shift in process from analogue to digital representations, most argue that technology can motivate human choice, but not replace it. Therefore digital technology is not necessarily unjustified or wrong, but argued against because of design creation¹⁰ processing become marginal and engineering becomes mediocre. Lanier (2010) argues that the deep meaning of personhood is being reduced by illusions of bits. Since people will be inexorably connecting to one another through computers from here on out, we must find an alternative.

7.1 Conceptual Blending and Pastiche

Perception and action are interconnected at a structural level (Clark, 1999). It has been shown that physical actions are organized specifically according to their goal: e.g. the grip aperture is specifically correlated to the size of the target object. The execution of a simple grasping action implies taking into account not only the properties of the motor system but also the properties of the object that are relevant for the action: its size, shape, texture. In a sense we can say that it is a pragmatic representation of the object (Jeannerod, 1994). These two conditions (perception and action) suggest that there are not only two types of visual perception, one to identify and the other to localize, but also two types of action, one descriptive and the other operational (Jeannerod, 1994). However, things are not as simple as might be construed here. The notion of constructing a tool based on perception and intention in action has also fundament in learning-by-doing, knowing-in-action, and thinking-on-your-feet (Schön, 1992). The negotiations between abstract and material representations (analogies) are instrumental to thinking. Analogy has traditionally been viewed as a powerful engine of discovery, for the scientist, the mathematician, the artist, and the child. In the age of form, however, it fell into disrepute. Analogy seemed to have none of the precision found in axiomatic systems, rule-based

¹⁰ *'La vraie creation ne prend pas souci d'être ou de n' être pas de l'art.'* - Jean Dubuffet (1986)

production¹¹ systems, or algorithmic systems. The moment these powerful systems came to be viewed as the incarnation of scientific thinking, analogy was contemptuously reduced to the status of fuzzy thinking, and mere intuition (Fauconnier & Turner, 2008). However, analogy, affect and metaphor are crucial in our thinking and working operations. Employing a physical prototype in a real context of use often reveals unanticipated information, which is one of the strength of physical prototypes, as shown in Figure 91.

Figure 91. *Conceptual blending and pastiche*

Material representations are external representations, the ability to reconfigure and reinterpret material representations is where their power lies in helping designers to think and learn (Brereton, 2004). In addition deploying computational assistance could enhance the processing, experience, interaction, and creativity. Combining realms for conceptual blending and pastiche scripts could enliven the creative process and affect the co-creational aspects in outcome, goals and actions, as shown in Figure 94. Pastiche allows to instantaneously evoking resonant contexts in which to place a new design, possible solution or think about user needs (Blythe & Wright, 2006). We consider pastiche as a style that imitates that of another work, instance, blend or design icon. It has been argued that it is not possible to predict the goals or actions of users without knowing anything about them (Nielsen, 2002). One of the principle advantages of pastiche scripts is that they are fun to make. They engage the designer and lead to fresh insight because the traits and quirks of the characters have nothing to do with the technology being imaginatively road tested. Pastiche scripts are certainly not presented as an alternative to more traditional scripts rather they are suggested as a complementary and fun addition to the HCI toolkit (Nielsen, 2002). So, we hypothesize that we need tools for thinking, conceptual blending and pastiche, tools that help and assist us in ‘streamlining’ our thoughts, patterns, ideas, and notions on specific topics, problems that need to be solved. What we need are challenging design spaces, eco-systems that turn the whole traditional design and engineering world upside down, and replacing it with the bubble-up image of mindless, motiveless

¹¹ *‘Society constructs its own delirium by recording the process of production; but it is not a conscious delirium, or rather is a true consciousness of a false movement, a true perception of an apparent objective movement, a true perception of the movement that is produced on the recording surface.’ - Deleuze & Guattari (1983)*

cyclical processes churning out ever-more robust combinations until they start replicating on their own, speeding up the design process by reusing all the best bits over and over, as shown in Figure 92 and Figure 93 (Dennett, 2013). In such that we have to ask ourselves, e.g. how two ideas can be merged to produce a new structure, which shows the influence of both ancestor ideas without being a mere ‘cut-and-paste’ combination? (Boden, 1996).

Figure 92. Low-resolution analogue modelling

Figure 93. Virtual digital and 3-D AM modelling

7.2 Natural Play, Interaction, and Hybrid Design Tools

Another set of hybrid tool environments for individual and collaborative interaction were developed to facilitate and accommodate the formerly described cyclical processing. The tools afford natural play and game-like interaction, as shown in Figure 94, in conjunction with the preferred design methods or process models (Wendrich, 2013a), (Wendrich, 2013c), (Wendrich, 2013d), (Kosmadoudi et al., 2014). In general design methodologies and process models have similarities across disciplines (Birkhofer, 2011), (Gericke & Blessing, 2011), the core of these are common design stages or phases and propose a stepwise, iterative process. A wide variety of authors identified and compared these design methodologies and design process models in mechanical engineering, service design, mechatronics and other disciplines, e.g. (Archer, 1964), (Cross, 1984), (Pahl & Beitz, 2005), (Kim & Meiren, 2010) that

created some sort of consolidation on commonalities across disciplines. Of course when reviewed extensively the crossovers become apparent and show common threads, patterns and themes no doubt. However, the different studies on design methodology are also fragmented and flawed by gaps in understanding, insight in context, and properly defined frameworks. Current and future development of design methodologies are in need of reformation since they are often insufficient, comprehensive, and long-winded that implementation and/or adaptation in industry still is reluctant and partially successful (Birkhofer, 2011). To keep-up with the fast and rapidly changing world, design methodologies should be adapted, developed, and reformed to adhere to the increase and need for multi-disciplinary collaboration in design processing due the rising complexity in design problems (Gerick & Blessing, 2011). The deployment of computers (i.e. CAD), play a very important, frequently dominant, and decisive role in design processes, not only in industry (business), but also in education¹² (10). However, most design methodologies only partially meet and/or favor computer use (Birkhofer, 2011) and could not keep pace with computers.

Figure 94. Pick-up game and free play

7.3 LFDS Extended

Nowadays the need for Web-based applications that runs in a web browser (WebGL API) is growing and allowing for more flexibility, mobility and freedom in use, usability, accessibility, and co-creation in the design and engineering development process (Wendrich & Helmich, 2014b). Needless to state, that the authoring and building of such a tool places greater emphasis on the performance, correctness, and availability of the Web-based system. However, to be able to access such a web-tool anywhere, anytime could help and support the ideation and creativity process without immediate constraint from place, time or location. Fundamental is access to the Internet though and sufficient bandwidth. The tool named Cross Sectional Design Synthesizer (CSDS) we currently develop, deploy, and test, is an extension on the LFDS framework. Our basic assumption is to use raw cross sections (from artefacts and objects) and build 3-D volumes in the virtual web environment, as shown in Figure

¹² 'Civilization is a race between education and catastrophe.' - H.G. Wells (1866-1946)

95 and 96. The initial tests show promise, however still crude in functionality, features, representation, and interface modality the prototype of the system works. The Web-based application consists of information content, and software required for the delivery of the content, to assist in maintenance and quality assurance of the content, and to provide various interactive capabilities. Furthermore, we still have to further develop the information structure, libraries, information content, interface layout, and navigation mechanism including possible use of interface devices. The proto-Web-tool runs on the Chrome Web-browser and uses a HD video camera to capture the real-time interaction. The 3-D cross-sectional build with shapes to serve a path from any number of cross-section-shapes and becomes the framework that holds the cross-section's forming a loft object (3-D object). However, this last part has not been formalized in the prototype at this point in time. In Figure 97 we show the current prototype user interface. Follow link to watch tool interaction and functionality: <https://vimeo.com/176298183> or try it yourself: <http://rawshaping.com/r/csds>

Figure 95. *Concept of CSDS Web-App*

Figure 96. *Virtual Simulation of CSDS Web-App*

Figure 97. User Interface of CSDS Web-App

7.4 3-D Intuitive Voxel Shaping Tool

This section describes the prototype of a 3-D intuitive sketching and shaping tool for free real-time three-dimensional sculpting, shape transformation, simulation and representation of voxels in virtual space (Wendrich & Goethals, 2013e), (Wendrich, 2014b). The hybrid design environment and synthetic tool afford the user to automatically modulate and oscillate form and shape through the application of various form finding and generating algorithms. The system helps the designer or user to explore the virtual design space more extensively than with conventional methods. The designer should be able to intuitively interact with the system, selecting, tinkering, tweaking, working on different levels of the design and making design decisions whilst the system dynamically performs modifications. The system will work as a tool for prompting creativity, opening up the designers' mindset to new possibilities within the virtual design space. Creating a dialogue between designer and algorithm, a process in which the designer feeds off the algorithm and vice versa. The system will consist of two devices: a front-end and a back-end. Initially, working within a virtual realm, the system should accommodate the exchange of analog to virtual representations of artefacts and vice versa, blurring the boundaries¹³ between both realms and making it possible for the system to be incorporated in the entire design process.

¹³ 'A man could be a lover and defender of the wilderness without ever in his lifetime leaving the boundaries of asphalt, powerlines, and right-angled surfaces. We need wilderness whether or not we ever set foot in it. We need a refuge even though we may never need to go there.' - Edward Abbey (1927-1989)

Figure 98. *Use Interface and 3-D Voxel Visualizations*

The front-end will be a means to view and interact with form and shape transformations. This can be a lightweight device with a hands-on interface for easy manipulation by the designer. Dynamically displaying forms and channeling modifications by the user, as shown in Figure 98. An intuitive interface is developed to make it possible for the user to interact with and manipulate forms in such a way that it will be easy for the user to simultaneously navigate both 3-D and virtual design space. It enables to work with a large amount of degrees of freedom, to sample hyper-planes at high speeds, and place boundaries within the design space. It is important to research suitable ways of human computer interaction for such a system, using various methods of interaction including; touch screens, cameras, gestures and other forms of sensors. The back-end will be for performing form generating algorithms. This should be a heavy duty machine that can perform iterations at high speed and can store large amounts of data. The algorithms will generate a large amount of data from design iterations; these should be stored so they can be easily accessed by the front-end interface. Also, results of human interaction should be stored, so the user can reverse certain decisions. This result for example in trees morphing end results over a set of decisions made a number of steps earlier. Various form finding/generating algorithms had to be researched and developed simultaneously with finding possible modes of interaction methods. Furthermore, the system should accommodate the exchange of analog to virtual representations of artefacts; we did research on 3-D scanning and various techniques (e.g. structured light, single camera, time of travel). Currently there are two ways to represent a 3-D model; Polygons and Voxels. Currently the dominant paradigm for 3-D modelling is based on polygons this allows for a much more open universally useful system (e.g. Blender). Polygon modelers only model shells. Solid modelers are usually limited due to the use of standard geometry and performing basic binary operations. They do not support importing of 3-D scanned data or the generation of complex geometry. However, they allow for parametric modelling, and precise measurements of design dimensions. They usually lack any form of parametricism or precise measurements (e.g. Sculptiris). The system should have a method for implementing or controlling algorithms, common ways are visual programming or scripting (e.g. Max/MSP, Grasshopper). A scripting language is a simple programming language that can be interpreted on the fly. We did several experiments to test the validity of the 3-D tool that made use of processing and toxiclibs volumetric library. The idea is to use a 3-D brush that allows one to sketch/shape out material in 3-D virtual space. After a number of tool iterations we made a tool setup which uses the accelerometer from the Smartphone, to rotate the camera around the object and a standard mouse to draw or paint, as shown in Figure 99. This allows

for a far more accurate controllability. Also an added feature is to use a controller parameter to change the size of the brush. This already allows for some nice and intuitive modelling technique. Given a little practice, quite a high level of intentionality can be acquired. This tool still only uses a spherical brush. The level of detail is quite low, due to resolution limits (64^3 voxels). Follow link to watch video: <https://vimeo.com/73946341>

Figure 99. *SmartPhone and Mouse - Bi-Manual Interfaces*

Higher resolutions result in lower frame-rates, and less of a fluid user experience, illustrated in Figure 100. Because processing and the toxiclibs library only allow for a spherical brush, and besides this it is limited in resolution we decided to make our own voxel engine using C++ and openFrameworks (<http://openframeworks.cc>). This version does not use a marching cubes algorithm, since the resolution of the voxel-space is high enough to simply draw a dense point-cloud. (If a point-cloud is dense enough, it will appear as a kind of solid shell), as shown in Figure 100. We use the mouse to control brush position, relative to the camera plane.

Figure 100. *Voxel Modelling and 3-D Visualization*

The right mouse button functions to position, whereby the left mouse button is to draw or paint. The Smartphone screen interface is incorporated to simultaneously control brush rotation or scale. The implementation of the self-build voxel engine, allows for the use of a higher voxel resolution

(volume spaces of up to 1024^3 voxels). Furthermore, the use of brushes in any shape or form is also possible. Besides it allows for the use of GPU acceleration and MultiThreaded CPU use. Programming our own voxel engine resulted in overall better performance, as illustrated in Figure 101. A simple brush selection tool was implemented (library), so multiple brushes can be used on one artefact, as shown in Figure 102. This takes the form of a matrix, displaying an overview of all the brushes one can use. The software uses an ambient occlusion rendering technique, to automatically create darker patches in places that receive less light from ambient environment. This is a fast rendering method that emphasizes and defines the structure and shape and form of an artefact.

Figure 101. *Voxel 3-D Interface View*

We use a stochastic method (Melsa & Sage, 1973 - 2001) for calculating lighting results in a characteristically grainy effect that underlines the raw and unpolished nature of the models (Wendrich, 2010a), (Wendrich, 2010b). On top of that, subtle directional lighting is added which casts directional shadow, this further emphasizes the spatial qualities of the artefact. Brush stroke can be the result of a translation, rotation or scale operation.

Figure 102. *3-D Brush Selection Tool Library*

Figure 103. *Iterative Voxel Shape Translation and Rotation*

Figure 104. *Iterative Voxel Shaping Combination*

Figure 105. *Volumetric Erasion*

Figure 106. *Volumetric Pattern Representation*

More interesting results start to arise when combinations of these three modalities are made, as shown in Figures 103 and 104. A brush can also be used as an eraser, subtracting material from an artefact or shape iteration. This technique can be used to create cavities or holes, and also to shave off material, as illustrated in Figure 105. Another interesting technique is the creation of patterns, by applying a technique analogous to stamping, or quickly dabbing a structure. Furthermore it is easy to create patterns by connecting, and interlocking brushstrokes as parts in a whole, creating complex structures, as shown in Figure 106. One of the most powerful techniques we discovered during testing was the use of recursive brushes. The tool will be based on this very much recursive way of thinking, tools and results being interchangeable. This recursion ensures the possibility of an iterative process, moving freely through different steps of the virtual design space. Therefore the tool will have two basic 'rules' or 'paradigms':

- 1) Forms can be moved through space, and this will create new forms
- 2) New forms can in turn be used to create new forms

From these two simple rules: advanced shapes can be formed, as shown in Figure 107. Movement is not limited to linear motion, but can also contain rotations, scaling, deformations, and even other movements. Since the brushes are essentially the same data structure as the canvas, the canvas and brushes are interchangeable. The use of painted artefacts (or parts of) as brushes to create new

artefacts allow the quick creation of complex geometries out of simple origin geometry, as shown in Figure 98 at the beginning of this section.

Figure 107. *Volumetric Recursive Iteration*

7.5 Collaborative Cloud Design Space (CCDS)

The latest addition to our set of hybrid design tools is a web-based design space for real-time collaborative interaction, short name CCDS (Goethals & Wendrich, 2014). We deployed a cloud-based architecture whereby the server stores the designs continuously and the clients can interact, edit and view the designs uninterrupted and fluidly. Clients can be different devices with access to the Internet and capability to run the software whereby they all view the same dataset simultaneously. The advantage is that clients can work (design) on the dataset without the need for different versions stored on different computers. The interoperability and multi-modality of the CCDS supports various tools, devices and serves as proscenia to the virtual design space. The use of one central server guarantees that the data stays consistent between the various clients. In Figure 108 the cloud architecture (client-server) is shown, including a LFDS hybrid design tool, laptop/pc and smart devices.

Figure 108. *Web-based Tools (CCDS) for Volumetric Recursive Iteration*

The system architecture diagram is shown in Figure 109. The complete system is based on Open-Source software implementation of Javascript, WebGL, Three.js, SnapSVG, Node.js, Sovkets.io and Neo4J.

Figure 109. CCDS - Client-Server Cloud Architecture

The current user-interfaces are a keyboard and mouse for laptop/pc, multi-touch will be used for smart devices. Further research is needed to investigate the use of other more intuitive interface modalities to support the user-interaction.

7.6 CCDS Extended

The current version, available online <http://162.243.105.67:8001/>, is in an experimental phase. The user-interface (UI) is easy to use and based on open design and software that enables collaboration and interoperation (Fig. 110). The concept is based on three central points:

- A collaborative, version-controlled workflow
- A non-hierarchical, modular, open and extensible user-interface
- A simple, powerful 2-D and 3-D Modelling Engine

Figure 110. CCDS - GUI

The CCDS is developed in such a way that everybody can contribute and add to the toolchain. For example a simple and easy way is to write an internal tool, whereby the internal Geometry Engine (GE) is used to generate or morph shapes and structures. The Collaborative Design Space uses Three.js to render its 3-D environment (Fig. 111). However, it uses its own geometry engine to allow you to easily generate complex geometries. The internal graphic user interface (GUI) elements can be used to create a pleasant interface (Fig. 112). Another way to interact and contribute to the CCDS is to write an external tool, in this case you can use any language and with use of an Application Programming Interface (API) the CCDS can be accessed. The API to be used for temporary access is HTTP json api, this is to up- or download data like 3-D models, images and other content. It is also possible to stream real-time data from for example sensors, in this case sockets/websockets are required. A websocket is a protocol that provides full-duplex communication channels over a single Transmission Control Protocol (TCP). A complete programming tool should consist out of the following features:

- the actual function
- a GUI
- optional physical UI
- definitions
- documentation
- thumbnail
- presets and tags

Further research, prototyping and agile development are needed to create a richer and more enhanced experience with the CCDS. In addition the Open Design and Access aspects should be explored and investigated further in future (Goethals & Wendrich, 2014).

Figure 111. CCDS - GUI and Iterative Generated Content

Figure 112. *CCDS - GUI and Iterative Generated Content*

7.7 Conclusions

Our hypothesis that embodied imagination (physical experiences and its structures), intentionality, and cognition could simultaneously 'link' this imagination (individual or collaborative) with the digital realm based on natural and intuitive interaction and exploration show promise in a number of aspects. The question remaining is to what extent and how much control should be handed to the machine in user-choice and decision-making? Our approach is to have the user involved as much as possible, in such the tool (machine) is like any other tool a mere extension to the physical realm to facilitate and/or aid in a specific task. The proposed holistic framework encompasses mixed realities with tangible exploration transferring another perspective on usability, processing and interaction scenarios within HCI and user experiences and engagement in the creative domain. We have executed various experiments and tested different hybrid tools, configurations, and software architectures to create an intuitive HCI in mixed reality. We used standard components (COTS) and computational complexity of algorithms to author and build working prototypes of the proposed hybrid design tools. We made progress in some areas of intuitive user interaction, and interface design, however results from tool use are still very coarse and rough to make any predictions or preliminary conclusions. To conclude, seen in the context of a full-fledged hybrid design process, confluence in translation of real-world artefacts or objects from and to the virtual realm should be continued to investigate and explore. Further research should be done on Web-based applications, real-time representation, lofting and shape dynamics, exporting geometry to 3-D printable file formats, and import of 3-D scan-data. The presented and discussed projects are part of our on-going research and development of intuitive hybrid design tools for design and engineering processing.

RST Research Timeline

ABSTRACT

The umpire whispers: “Please Play”. We sort of play. But it’s all hypothetical, somehow. Even the ‘we’ is theory: I never get quite to see the distant opponent, for all the apparatus of the game (Wallace, 2011). We find no reason to abandon the notion of play as a distinct and highly important factor in the world’s life and doings. All play means something. If we call the active principle that makes up the essence of play, ‘instinct’, we explain nothing; if we call it ‘mind’ or ‘will’ we say too much. However we may regard it, the very fact that play has a meaning implies a non-materialistic quality in the nature of the thing itself (Huizinga, 2014). This chapter builds on the notion of integration of creativity and play in design and engineering environments. We show results of ongoing research and experimentation with cyber-physical systems (CPS) and multi-modal interactions. The use of computational tools for creative processing and idea generation in design and engineering are mostly based on commonly available 2-D or 3-D CAD programs, applications and systems. Computer-generated creativity is mostly based on combinatorial power and computational algorithms of the intrinsic system duly orchestrated by the user to manifest outcomes on a variety of processes. However, integrated game-based CPS ecosystems could enhance the uptake of play, imagination and externalization within the design and engineering process.

CHAPTER 8

Blended Spaces for Integrated Creativity and Play in Design and Engineering Processes

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8.1 Humans, Machines, Systems and Interaction

Humans, machines and systems are incorporated, embedded and take fully part in all areas, sectors, territories, and domains of our 24/7 economy to fulfil, assist or support our daily tasks, work, communication patterns and lives. Everything seems connected or is connected by some sort of means, service or proxy. Consequently we immerse ourselves in analogue and digital realms seemingly effortless, constantly meandering between real and virtual environments. There is hardly an escape or possible denial of the digital revolution in our daily routines from technologically communicated, facilitated, and/or (hyper-) mediated interactions.

Although computers are encroaching into territory that used to be occupied by people alone, like advanced pattern recognition and complex communication, for now humans still hold the high ground in each of these areas (Brynjolfsson et al., 2011). People can excel in interactions and communication with others and possess amazing capabilities to use these complex skills to gather information or have an influence on others behaviour. However, computers and systems are getting better and better in doing virtually the same complex set of sensorial ‘understanding’ and recognition of recurring motives.

Virtual assistants are quite common practice these days (i.e. services, communication, and information) and are often more cost-effective and efficient in their repetitive task fulfilment and core functionalities. Humans continue to have, at least for the time being, an advantage in the physical domain in which they use their abilities and capabilities in often advanced and complex situations in either physical or cognitive challenges (i.e. communication, psychology, cognition). In general, people are great problem-solvers in the physical and metacognitive processes, often ambiguous, non-linear, uncertainty, predictable or unpredictable but always in the state of motion, intent and interaction. Putnam (1981) points out that any adequate account of meaning and rationality must give a central place to embodied and imaginative structures of understanding by which we grasp our world. The structure of rationality is regarded as transcending structures of bodily experiences (Fig. 113).

Subjective	—————	Objective
Mind	—————	Body
Liberal Arts	—————	Natural Science
Human / Person	—————	User / Customer
Internal	—————	External
Implicit	—————	Explicit
Virtual	—————	Physical
Experiential	—————	Practical
Human-Experiential Design	—————	User-Experience Design

Figure 113. *Transcending structures of bodily experiences*

Human reality and experiences are shaped by the patterns of our bodily movements, the contours of our spatial and temporal orientation, and the forms of our interaction with objects. It is never merely a matter of abstract conceptualization and propositional judgments (Johnson, 1987). Our

hypothesis is that embodied imagination (i.e. physical experiences and its structures), intentionality, and metacognition could simultaneously 'link' these physical and mental faculties (individually or collaborative) congruously with the digital realm based on our natural physical and intuitive interactions and explorations. The deep meaning of embodied cognition is that it enables disembodied thought (Tversky, 2005). The key question here is: Are embodied representations, our expressions developed from our bodily perceptions and imaginative systems of understanding adequately shared to be thought of as appropriate to knowledge? Or are they too subjective, unstructured and unconstrained? To paraphrase Johnson, "...there is alleged to be no way to demonstrate the universal (shared) character of any representation of imagination" (Johnson, 1987). There seems to be an undeniable oscillation between objectivism and subjectivism that could lead to relativism. According to Schön (1983) it seems right to say that our knowing is in our action and interaction. In the fuzzy front end of creative processes ideas are often visualized in one's imagination and externalized through 2-D and/or 3-D representations. Rationalizing these ideas using 'supportive machines' (virtual assistants) is of primary concern for RST research. Instead of externalizing only the final results of a creative process, recording the separate iterative steps of the process can help in rationalizing the thought process. Furthermore, an overview of previously created representations can lead to new insights and richer ideas, whether these representations are physical or virtual (Fig. 114).

Figure 114. *The four dimensions along which representations can be classified in design processing*

Brereton (2004) describes four dimensions along which representations can be classified (Fig. 114). We concur with Johnson (1987), that imagination is recognized to play a role in the "context of discovery," wherein we imaginatively and iteratively generate new ideas, concepts and connections; but it is excluded from the "context of justification" which is restricted solely to the tracing of logical connections (objectivism).

Linking both analogue and virtual worlds, as shown in Figure 46, 62 and 113, was already present during the initial wake of the computer-revolution; the idea of 'disembodied cognition' became very popular (Tversky, 2009), (Mahon et al., 2008). The trouble here is that being 'disembodied' created great challenges, frustrations and problems to solve in human interaction with machines. Virtually

everyone agrees that human experience and meaning depends in some way upon the body, for it is our contact with the entire spatio-temporal world that surrounds us (Wendrich, 2014c), (Wendrich, 2015b). Embodied understanding is a key notion, we are never separated from our bodies and from forces and energies acting upon us to give rise to our understanding (our “being-in-the-world”). So, this “being-in-touch-with reality” is basically all the realism we need. This realism consists in our perceptions and sensorial understanding that makes us feel, touch, explore, and come-to-grips with reality in our bodily actions in the world. Moreover, we need to have an understanding of reality ample enough to afford us to fulfill a purpose or task nearly successfully in that “real” world. Polanyi (1966) describes the human body as an instrument, the only instrument that we normally never experience as an object. Because we experience our body in terms of the world to which we are attending from our body “...we feel it to be our body, and not a thing outside” (Polanyi, 1966).

8.2 Blindfolded, Tangibility, Tacit and Haptics

Direct demonstrations of embodied and disembodied views of conceptual representation are shown in the following experiment we conducted. The aim of the experiment is to measure, observe and quantify tacit and tangible knowledge through haptic representation without visual clues. Polanyi (1966) stated the fact, by reconsidering human knowledge, that we can know more than we can tell. When we touch something with our hands or with a tool our awareness of the impact is transformed into a sense of what thing or object we are exploring. An interpretative effort transposes meaningless feelings into meaningful ones (Wendrich, 2011b), (Wendrich, 2015b). According to Collins (2010) this is the semantic aspect of tacit knowing. In this experimental setup, we will need to both assume a relatively low prior knowledge of the user and aim to reduce the required knowledge to complete a given task as well. As such we need to take a look at the lowest common denominator in terms of prior knowledge and the required level of knowledge a user needs to have to complete a given task with our interface. The gap between the knowledge a user already has and the knowledge a user requires to complete a given task is our research focus in intuitive interfaces, multi-modal processing, and hybrid design tools (Spool, 2005). In order to achieve this, we draw on associations and metaphors that common users are already familiar with in real life. At the same time we acknowledge and recognize the aspects of uncontrollable bias, uncertainty, approximation and unpredictability in real and synthetic environments (Wendrich, 2010a), (Wendrich, 2011b), (Wendrich, 2014b), (Wendrich, 2016d). The participants, 158 university bachelor students (male and female) industrial design engineering, were all blindfolded during the execution of the conceptual processing tests (Fig. 115, Fig. 116). Blindfolded participants were given either aural instructions, or tangible instructions in recreating an automotive artefact (idiosyncratic design icon). Seventy-nine participants were given an audio cue (disembodied), a wire size constraint, and a set-of-wheels (Fig. 117 - left). The set-of-wheels were for the users to fix to the clay-model in order to see if they had a certain sense of spatial-temporality to position them more-or-less correctly in their tangible model. The other seventy-nine participants got a scale model (embodied) of the iconic car (boxed) (Fig. 117 - right). The user-task was to make a tangible representation in either green- (tacit-haptic) or red-clay (tangible-haptic) with a time limit of five minutes (Fig. 112). By using solely haptic perception, in one case aided by aural instructions, the participants had to identify, recognize, re-create, mimic and make a 3-D representation of the shape (Fig. 118 left and right). End-results from tacit-haptic interaction (green models) and tangible-haptic processing (red models) showed great differences in shape and form, quality, structure, configuration and representation (Fig. 119).

Figure 115. Setup blindfolded conceptual design processing

Figure 116. Multimodal user interaction during blindfolded experiment

Figure 117. Setup tacit tangible (left) and tangible haptic blindfolded cues (right)

Figure 118. Tacit haptic (left) and tangible haptic (right) representation

Figure 119. End results of tacit haptic and tangible haptic processing (selection)

The experimentation showed that haptically sculpting with a tactile role-model gave a greater precision, mimic and resemblance to shape and form in contrast with users that solely relied on aural and tacit input. The results show interestingly the differences in both approaches and approximations, thereby illustrating the apparent dominance of using the senses of touch and proprioception. However, this is not to state, point out, and /or argue, that the green models are of “less” interest, little value or quality. On the contrary, both sets of end-results show the meaning and difference in use of sensorial and meta-cognitive representation and externalization. Furthermore, the absence of visual input during the design process results in an explorative nature (metacognition) of the process. The importance of tangible feedback becomes apparent for the understanding of shape and intuition in representation. Although visual input is extremely important in a design process, tangible feedback forms a substantial part of understanding shape and cannot be neglected as input for design tools (Wendrich, 2011b).

8.3 Blended Spaces and Tools

Reflection, incubation and learning are encouraged when technology is supportive and calm, it allows user-control, engagement and foster learning skills while harnessing talent (Wendrich, 2014c). A lot of research is being directed in the past/present towards human-computer-interaction (HCI), exploring the functional cognitive seams, and will continue so into the future. McCullough (1996) calls this “human-computer partnership’s” that will be developed to make the interaction more superfluous and natural feeling. Many argue that it is not really necessary to mimic the real phenomena in the virtual or to create sameness in experience and representation within synthetic worlds. This is partly true for maybe some virtual areas, like for instance gaming as entertainment or playing in virtual realms. When it comes to creativity, serious gaming, design, manufacturing, and engineering the need for real world reflection, recognition and mimesis is often a prerequisite for successful simulated experiences, processes and interactions. Knowledge development and acquisition is a resource in the constructions and representations. A wide variety of tangible and virtual models are constructed and used to support the processing and communication. According to Sellen and Harper (2002) studies with computer supported collaborative workspaces have shown that artefacts such as ‘pencil and paper’, play a critical role in supporting social interaction and collaboration. For designers, paper-based sketches and low-resolution modelling have also shown coordinative advantages (Baskinger, 2008). In the HDTE the user is central in the design processing and interaction multimodalities. The experience of the HDTE aims to achieve a richer and more serendipitous design and engineering process that include the integration of distributed cognition, experiential learning and augmented representation during conceptualization and ideation. Figure 120 shows a HDTE and a suggested flow diagram indicating the design processing whereby the user (-s) is rendered in-the loop. The blue arrow represents the meta-cognitive interaction between tangibles and the meta-physical perception of the user. The green arrows represent different types of reflection that can occur during the process. Findings and preliminary conclusions on various modalities (e.g. analogue, digital and hybrid) in tool use, interaction and processing showed remarkable correlations and differences between user knowledge, experience, expectation, performance and motivation, as shown in Table 7.

Figure 120. HDTE – user-in-the-loop design process flow diagram

Table 7. Online user feedback triple helix design tools interaction and processing

Questions	Results		
	Analogue	Digital	Hybrid
Previous experience with design tool? (%)	100 % yes	85 % yes	7 % yes
What is your experience with design tool?	Intermediate	Intermediate	Novice
The tool was easy to use?	Agree	Disagree	Agree
The tool facilitates easy recovery?	Neutral	Agree	Neutral
The tool supports fast productivity?	Agree	Neutral	Agree
Design task performance is fluid and direct?	Agree	Sporadically	Always
How does tool meet your expectations?	Very good	Mediocre	Good
My creative output was successful?	Minor problem	Problem	No problem
The interface of the tool is pleasant?	-	Agree	Agree
Exploring software features by trial and error?	-	Hard	Easy

Notably, in the early design and engineering phase the role of tools is noteworthy, especially in terms of what kind of tools to choose, decisions have to be made about what kind of process to use and how? Furthermore, every choice and decision has its direct, explicit and implicit implications on the individual task, outcome and process as a whole. A hybrid tool can provide a continuous challenge between the visual and tangible representation (Fig. 121). New users learn to use the tool through exploration and experimentation. Virtual tools offer advantages like e.g. sharing information, metadata, visual representations, and simulation. However, due to high learning curves, the design process with these tools is rigid, non-intuitive and limited in stimulating creativity. Gameplay on the other hand tends to be regarded as memorable and formative experiences. Intuitive, imaginative, stimulative are attributes that spur natural creativity. If games are profoundly imbued for purposeful play, thriving on tacit and explicit knowledge of the user, a CAD system carefully stylized with ludic mechanisms could potentially be highly productive (Kosmadoudi et al., 2013). In most CAD systems, designers are required to change their skill-sets to meet the demands of the interface, instead of changing the interface and functionality to their demands.

Figure 121. HDTE – continuous challenge between real and virtual representation

8.4 Pairwise Comparison of HDTE Tools

A pairwise comparison interaction experiment with two HDT's (i.e. LFDS & NXt-LFDS) (Wendrich, 2014 a-b-c and Matlung, 2015) are executed to generate user interaction (UI) and user experience (UX) data required for the analysis and evaluation. Both tools are set up together for the benchmark test (Fig. 122). A total of fifteen participants ($n=15$) were asked to perform a design task with one of the HDT's. All participants were university bachelor students industrial design engineering. We tested 8 students (5 males, 3 females) on the NXt-LFDS and 7 participants (5 males, 2 females) on the LFDS. We placed

one participant per HDT, executing the design task simultaneously so they could have a more engaged experience. After approximately 12-15 minutes they changed machines. Total interaction time is 25-30 minutes; we anticipate that the users (user-groups) can provide more profound feedback on the usage and interaction. The design task was to ideate and conceptualize a hydrogen car from scratch. The aim is to get as much iteration as possible within the specified time (aka iteration galore) (Wendrich, 2014c). Some 3-D AM tangible artefacts (i.e. wheels, motor, and hydrogen fuel cells) were supplied to act as metaphorical constraints (Fig. 123). Furthermore, they had access to traditional design tools, paper, constructing materials and so forth.

The collection of data consists of three main methods;

- Observations; of both facilitator and by video analysis
- On-line Survey; user feedback on several IA issues
- User Results; process, speed, performance, iterations and user created content

We extract the data on usage, interaction and relations between input and output. The acquired data will be evaluated and analyzed in order to provide the foundation for writing the recommendations and further development of the on-going research on RST-HDTE's (Wendrich, 2010a), (Wendrich, 2011b-c), (Wendrich, 2012a-b), (Wendrich, 2013a-b-c-d), (Wendrich, 2014c), (Wendrich, 2015a), (Wendrich, 2016a-b-c-d).

Figure 122. Pairwise comparison of HDTE tools: LFDS (top) and NXT-LFDS (bottom)

The participants received a short introduction on the working of the HDT's before they started the design task. However, most of the participants still asked for help with certain functions that seemed intuitive at first. Most users first showed some caution in trying different features and exploring possibilities. The 3-D sensorial space of the HDT's was not clear to almost all of the participants. They could not grasp this simple 'trick' of spatial perspective-taking and most started their iterations in 2-D representations. They placed the objects and constraints on the workbench thereby not using the capability of 3-D sensorial space to take a perspective snapshot of an object.

Figure 123. *Three-dimensional AM tangible constraint metaphors*

After a simple 'nudge' (facilitator) in the direction of the illusion of perspective some participants got the idea. Some needed a simple demonstration to understand the perspective visualization. Others needed just the words '3-D' and 'perspective' to make the connection. Nevertheless, all participants, except one, needed this 'nudge'. This gives an indication about the intuitive interface and blindspots of/ in user interaction and processing. The overall performance to create 3-D iterations in perspective and make real-time captures seemed difficult. Participants were observed (i.e. facilitator, video recording) and seemed to struggle holding artefacts and/or objects in the right position to make iterations. To place a physical object in 3-D perspective position is difficult and requires full body control, intrinsic skill-sets, manual dexterity, hands-eyes coordination, and strong visual-perspective prowess. Patience and relaxation is required to position objects in 3-D space. Some of the users clearly showed signs of frustration and lacked patience, experience, and motivation to fulfil the task successfully. This has direct implications on the generated iterative content, quality, performance, and direction of the iterative solutions. Finally, the NXt-LFDS monitor was more directly present for the participants due the embodiment design and architecture of the machine (Fig. 124) (Booij, 2013). The interaction with the NXt-LFDS takes place in the 3-D sensorial space underneath the monitor, compared to the LFDS; there is a sort of blind-spot where the users' hands are manipulating the artefacts and objects. The monitor physically obscures part of the interaction, therefore watching the monitor and virtual visualization becomes more prominent during interaction.

Figure 124. *LFDS versus NXT-LFDS user engagement (UE) and enjoyment*

We observed engagement and motivation during the experiment; however some participants did not quite follow the task and created “art” instead. If asked whether they would drive in such a car, they responded with ‘no’. The questionnaire revealed that they saw the tool more as a fun thing to play with, instead of using it to create conceptual solutions for real design problems. However, after users got the ‘hang of it’ (experiential) they started to become more and more creative in their iterations and use of the provided constraints and reflective materials (Fig.125). Most showed signs of enjoyment and pleasure. This is shown in the total of iterations made, the variety and diversity in iterative content through translation and transformation of the 3-D materials and objects. The figures clearly show the randomly selected results of the iterative hybrid design processing.

Figure 125. *LFDS and NXT-LFDS iterative virtual processing*

Over time the participants became more familiar with the tools and the interaction and outcome greatly improved. Video analysis and observations showed immersive interaction and signs of flow during processing. We identified concentration on the task at hand, non-distracted processing and focal intention on the interaction with the tools. The tools evoked serendipity in generated content, creativity, and stimulated the users to try out effects with different materials (Fig. 125, Fig. 129). A concern was to keep the motivation of some the participants, towards the end initial enthusiasm turned around and slightly faded.

Figure 126. Pairwise comparison of LFDS and NXT-LFDS

With all the issues and difficulties the participants addressed, one might think the experiment was not fun at all. On the contrary, all the users did enjoy the testing and found it insightful and enhance their creative and imaginative abilities. The participants gladly and willingly provided feedback and suggestions for improvements. In Figure 126 we show the pairwise comparison based on the former indicated features and aspects. In Table 8 and Table 9 we present the data that is evaluated and analyzed based on the user performance (i.e. quantity of iterations, speed, merged iterations), user interface (UI), processing time and user-experience (UX) (i.e. ease-of-use, usability, GUI). Data is taken from the 15 participants (See Table 11), as shown in the Table 8 and Table 9; the iteration per minute is 4.11. The amount is slightly higher than previous tests (24). With a total amount of 1108 iterations resulting in 77 merged results, referred to as 'Sketches' in tables. On average each user created 5.13 'Sketches' and used 14.4 iterations for each.

Table 8. Combined test results dual hybrid design tools (LFDS and NXt-LFDS)

Pairwise comparison of HDT's	
Interaction and processing	Totals
Number of iterations	1108
Excluding group number 4	1034
Start processing	771
End processing	337
Merged iterative instances (Mii)	77
Net processing time	4:29:28
Iterations per minute	4.11

Table 9. Data* of two HDT's generated from first and second round of experimentation

Pairwise comparison of HDT's		
	LFDS	NXt LFDS
Total number of iterations	561	473
Start	413	305
End	148	168
Total processing time	2:07:23	2:08:29
Start	1:35:07	1:31:07
End	0:32:16	0:37:22
Iterations per minute	4.40	3.69
Start	4.34	3.35
End	4.59	4.50
Task time	0:09:06	0:09:11
Start	0:13:35	0:13:01
End	0:04:37	0:05:20
Merged iterative instances (Mii)	35	35
Start	25	23
End	10	12

*Data taken from devices with respect to first and second rounds. The start round on LFDS and end round on NXt-LFDS are derived from the same user. Correspondingly for start on NXt-LFDS and end round on LFDS.

Table 10. Mean difference on first and second round experimentation

Pairwise comparison of HDT's			
	Merged iterative instances (Mii)	Time	Time/Mii
Start mean	3.53	0:13:18	03:46
End mean	1.60	0:04:58	03:07

Table 11. Detailed overview user statistics on experimentation

Pairwise comparison of HDT's (LFDS and NXt-LFDS)								
Group	Name	Tool device	LFDS iterations	NXt-LFDS iterations	Start Mii	End Mii	LFDS time	NXt time
1	Jeroen	LFDS	54	21	9	6	0:15:05	0:08:23
1	Michiel	NXt	28	32	8	5	0:04:05	0:11:04
2	Hilde	LFDS	51	25	6	4	0:09:46	0:06:59
2	Myrthe	NXt	21	28	5	3	0:05:01	0:05:25
3	Marco	LFDS	61	17	3	2	0:15:11	0:03:56
3	Peter	NXt	18	28	3	2	0:03:36	0:13:44
5	Mustafa	LFDS	47	7	3	2	0:12:48	0:02:17
5	Alicia	NXt	20	60	5	4	0:04:37	0:14:35
6	Thomas	LFDS	69	28	5	4	0:13:48	0:02:12
6	David	NXt	21	49	3	2	0:04:57	0:14:58
7	Elleke	LFDS	81	27	5	4	0:15:26	0:05:08
7	Klaartje	NXt	24	67	5	4	0:04:04	0:20:04
8	Rens	LFDS	50	43	6	3	0:13:03	0:08:27
8	Goffe-Jan	NXt	16	41	4	3	0:05:56	0:11:17
4	Pim	NXt	21	53	7	5	0:05:56	0:10:11

On both HDT's the second round resulted in a higher iterations per minute rate. Only the NXt-LFDS has a remarkable higher it/min rate in contrast to the first round. Likewise, the ratio between total start and end iterations is smaller on the NXt-LFDS compared to the LFDS. That is 1.8 for NXt-LFDS and 2.8 for LFDS. Furthermore, the mean difference between start and end, with respect to time per sketch, are displayed in Table 10. It shows a clear reduction of time needed per sketch on the second round. In Figure 127 findings and results are visualized in charts to show the data acquired per group. The iterations per person on both the LFDS and NXt-LFDS are shown in Chart A and B. It clearly shows the lower average iterations when users started on the NXt-LFDS. Also the means of starting and ending are much closer to each other compared to the LFDS. Remarkably, with the first three groups performing on the NXt-LFDS the iterations lay even closer to each other. Explanation of Chart A and B (Fig. 127):

Chart A: The iterations per user created on the LFDS. The first user of each group started on the LFDS.

Chart B: The iterations per user created on the NXt-LFDS. The second user of each group started on the NXt-LFDS.

Figure 127. Iterations/person on LFDS versus NXt-LFDS

Figure 128. Merged end-results and iterations on LFDS and NXT-LFDS

Furthermore, the amount of merged iteration results on both machines is within the same spectrum and shares the same average according to Chart C. Explanation of Chart C and D (Fig. 128):

Chart C: Showing the merged results per device for each group member.

Chart D: Shows the results from the participants on iterations per minute.

The zigzag pattern shows the difference in time users had on their respective rounds. The first round lasted on average 13m18s and the second round 4m58s, for reference see Table 10. The iterations per minute for all users are displayed in Chart D. Noticeable are the large discrepancies per user. For example, the highest is 12.73 compared to the lower of merely 2.

8.5 User Interaction and Experience with HDTE

The NXt-LFDS proved to be a genuine hybrid design tool merging analog manipulation in combination with digital virtual representation. Most users showed engagement while performing their interactions; they were motivated and concentrated during the processing. The number of generated iterations and possible solutions (Fig. 129) that were externalized, suggests the rationale and processing procedures behind these findings (Fig. 130). Still, a number of issues could break this ‘immersive state’, or flow, due to apparent user frustration and uncertainty in interaction modalities. Most of these issues on the NXt-LFDS are UI related.

Figure 129. *Iterative ideation galore processing*

Figure 130. HDT incremental design processing procedure

Figure 131. Iterated translations and transformations visualized on processing GUI of NXT-LFDS

The UI of a design tool is one of the most important aspects of such a tool, because of the direct representation and visualization implications of the digitized virtual content. It is the proscenium onto an individual or social virtual reality (Wendrich, 2010d), (Wendrich, 2014c) (McCullough, 1996). If designed perfectly, the user will feel no drawback or break the ‘flow’ (Csikszentmihalyi, 1991). The interface should therefore be operated on intuition (Fuzzy Mode) and not predominantly on logic (Logic Mode) as shown in Table 12 [See also Chapter 5].

Table 12. *The distinction between the fuzzy mode (FM) and logic mode (LM)*

HDT modality	
Fuzzy mode	Logic mode
Focus on physical modality	Focus on virtual modality
Unobtrusive technology	Prominent technology
Input devices used for content creation	Input devices used to control and create content
Benefits from reduced complexity	Overview of created content
Low amount of functions	Change, reorder, shift individual iterations
Obvious interaction styles	Recombine, reorganize iterations
Untethered interaction	Interactive GUI elements
Core functionality in plain sight	Enhanced and specific functionality
Tangible capture buttons	Menu structure with familiar icons and descriptions
New canvas selection	
Optional undo or delete function	
Mirror mode	
Overview and review mode	
Timeline iterative and merged instances	

From the survey we conducted, it became clear that the users rated the NXt-LFDS higher than the LFDS. The users experienced the NXt-LFDS to be an improvement of the earlier hybrid design tool (HDT). Although the users felt that the NXt-LFDS an improved design tool over the LFDS, the performance of the former was not exceeding its predecessor. Most of the issues can be translated to the graphical design of the UI. The NXt-LFDS uses a multi-touch monitor; the visual appearance seems more cluttered with next to the iterative content showing also the interactive buttons/features. Nevertheless, most of the users found the on-screen interaction more pleasant. The reason being that the focus and your concentration is often solely on the monitor, instead of having to revert back to the numpad (LFDS) for interaction. Still, the interaction proved to be counterintuitive in some functions/features. The numpad (Wendrich, 2010d), (Wendrich, 2013c), for instance, has each function in proximity of each other and on the graphical user interface (GUI) of the NXt-LFDS these functions/features are more integrated and arranged on-screen (Fig. 131). Recommendations for improvement and continual development of the GUI for the NXt-LFDS are necessary to intuit the user interaction and modalities. Furthermore, an important process step in tool-use comes parallel, during or after the ‘fuzzy front end’ (Fuzzy Mode); the Review modality within the so-called Logic Mode (Wendrich, 2013c) was only used for Select and Sort of iterations by some participants. Users, unfortunately, did not really intuitively understand the meaning of the features as implemented in the Logic Mode (Fig. 132). According to some the functionality felt sluggish and not fully functional to benefit from. The core of this Logic Mode needs to be redesigned to fit the vision of intuitive and superfluous interactivity in HCI and HDT’s.

8.6 Performance and Expectations HDTE

On both the LFDS and NXt-LFDS the start-off count of it/min were in general lower than the number of it/min after the switch of machines (second round). A possible explanation could be the initial experience of the users increased their performance and user behaviour. One remarkable aspect is the difference in the start and end it./min. on the NXt-LFDS. The difference is much larger compared with the LFDS. The lower iterations per minute on the start of the NXt-LFDS could indicate a higher learning curve and possible constraints of the user modalities. For example, the placement of the touchscreen above the physical-sensorial workspace impairs the vision during interaction with tangibles. The position of the adjustable monitor therefore is important at the start of the design process. None of the participants adjusted or asked for help in re-positioning the monitor. This shows how the perceived inherent system qualities are not self-evident and/or self-explanatory for users. Given that the sample rate overall was low, despite the fact that one user made an astonishing amount of +12 it./min. on the second run, the inherent higher value of mean it/min of the second run on NXt-LFDS can be due to this particular outlier. This could imply that the average will drop if we take this user out of the equation. This will make the difference between LFDS and NXt-LFDS even larger and suggests that the LFDS performance is higher and outcome in iterations per minute considerably larger. Furthermore, the average iterations per minute lay higher than in previous experiments. This possibly is due to the fact that the overall interaction and processing time was longer. The users could familiarize themselves with the machines. This in combination with the difference between starting and ending it/min, informs us how enhanced UX can play an intrinsic and active role in user performance and task execution.

Figure 132. Choice and decision making of iterations from fuzzy mode (FM) (top) in review pane of logic mode (LM) (bottom) on GUI of NXt-LFDS

This phenomenon seems self-evident but does not make transparent the whole issue. To create and design a ‘truly’ intuitive tool and UI, the difference in performance between an experienced user and a novice user should be minimal, virtually non-existent. When novice users start to work on the machines they showed signs of uncertain behaviour and a tendency to stall the interaction probably out of fear to make mistakes. The cognitive overload in concern of doing something wrong did not invite users to immediately try out the different features and possibilities of the machines. In this case a well-timed ‘nudge’ (Wendrich, 2011c), (Wendrich, 2013c) from the machine could trigger the user to start-off the design processing and user interaction.

Figure 133. Final results selection iterations in fuzzy mode (top) and tagged selections (bottom) on GUI of NXT-LFDS

For example, the machine could display or voice a message; "Place something on the workbench to start." Followed by; "Press the capture button (with an arrow directing the attention to the on-screen red button) to capture your work" (Fig. 133). Both machines could inform the user about the multi-modalities and tool specifics. If a user places an artefact or object in the sensorial space/ or workbench and forgets to capture this; the capture button could flash or blink subtle to indicate the user to capture the iteration. The overall performance, experience and user interaction could be improved by integration of functions, modalities, features, tools and sensorial actuators to enhance the workflow process. At the end of the sessions we noticed a drop in motivation and user performance. Currently we are analyzing the video footage and evaluate the user comments from our on-line questionnaires to determine what factors and/or issues led to this lack of interest towards the end of the sessions.

8.7 Conclusions

This chapter is part of our ongoing research and development of hybrid design tool environments, these preliminary findings and results show our variety in approach to tools, tools use, multi-modalities, and experimentations carried out to investigate the human-in-the-loop design processing and interaction. Although most users found the NXt-LFDS an improvement in relation to the earlier LFDS, the overall performance of the NXt-LFDS was not exceeding its predecessor. Most of the current issues can be translated to the interface design and the not self-explanatory functionality of the embodiment. Given that the NXt-LFDS uses a touchscreen with interactive widgets, the monitor looks more cluttered showing not only the iterative results but also functionality features. The LFDS makes use of a modified numpad with various function buttons. The overall performance of the LFDS in interaction and processing is rated better and quicker than the new machine. The embodiment is different, the monitor is further away from the user, the workbench/sensorial space is easy accessible for free physical tactile exploration. Interaction seems to be more intuited by design and appearance. Whereas the embodiment of the NXt-LFDS is aesthetically more pleasing, the functionality and interaction seems to ask more concentration and understanding from the users. The potential visual overload and closeness of the touchscreen appears to have a direct impact on the usability and performance. Even the relative easy adjustment of the monitor position does not effectively contribute to the initial uncertainty and discomfort of the user. However, during and after testing users seemed to enjoy the touchscreen interface and GUI. It was a matter of experience and understanding of the interface modalities that contributed to the increase in performance over time. The LFDS is perceived more 'intuitive' than its counterpart in the comparison; this is probably because of its simple and low-tech appearance in conjunction with the self-explanatory interface devices (e.g. numpad, red capture button, foot pedal). This correlates with Shirky (2010) who states, "...you don't need fancy computers to harness cognitive surplus; simple, cheap, flexible tools are enough". In video interaction analysis we witnessed enjoyment and signs of flow in interaction and user behaviour. This directly relates to the findings by Csikszentmihalyi (1991) on clarity of goals - knowing how well one is doing - balancing challenges and skills - merging of actions and awareness - avoiding distractions - forgetting self, time, and surroundings directs to flow and happiness (Csikszentmihalyi, 1991). The fast number of iterations made by the participants showed a plethora and serendipity in ideas and possible solutions for the concept design of a hydrogen car. Working with tangible and tactile artefacts and objects in combination with virtual artefacts made the participants perform and transform a huge variety and diversity in embodiments, assemblies and structures. Much reflection-in-action hinges on the experience of surprise. When intuitive, spontaneous performance yields nothing

more than the results expected for it, then we tend to think about it. But when intuitive performance leads to surprises, pleasing and promising or unwanted, we may respond by reflection-in-action (Schön, 1983). To continue the development of the NXt-LFDS, recommendations and improvements have been made for the redesign of the GUI, functional structure and embodiment of the machine. Another important aspect in the HDT design processing sequences are the steps taken parallel, during or after the 'fuzzy front end' (Fuzzy Mode), this is the Logic Mode to Review (i.e. select, sort, stack) and followed by Decision Making of tagged results or possible concept solutions. The Fuzzy Mode affords the externalization and generation of iterative ideation, in such that all thoughts and creative output are represented and transformed into virtual realities. This metamorphosis provokes material consciousness in three ways: through the internal evolution of a type-form, in the judgment about mixture and synthesis, by the thinking involved in a domain shift. The seduction of computer aided technologies (CAx) lies in its speed, the fact it never tires, and indeed in the reality that its capacities to compute are superior to those of anyone working out a drawing by hand (Sennet, 2008). The Logic Mode entails the Review Mode and affords the choice-architecture to synthesize the ideas, to create virtual concepts for individual or collaborative sharing (i.e. web, cloud or intra). This modality can be used any time through the duration of the processing, iterations can be collected and assorted for mixed or blended conceptualization of the final concept representation (Wendrich, 2010a), (Wendrich, 2013c), (Wendrich, 2014c), (Wendrich, 2016d). Most of the users (novice) did not understand or were clear about the possibilities and/or functionality of this specific modality. The current software on the NXt-LFDS is not 'robust' enough to support the interaction fluidly and congruously. Therefore, this feature felt sluggish and showed latency during use. This problem might have had some implications on the motivation and activity of the participants. To conclude we paraphrase Prensky (2001), "We the Game, we the CAx, we the People, we may well "make sense of novelty through the lens of history," defining "new technologies in terms of older, more familiar ones" (Moore, 2010) but that process can also be reversed. The transitional can operate both ways with adaptations" (Hutcheon, 2012). We shall not cease from exploration, and the end of all our exploring, will be to arrive where we started, and know the place for the first time (Macfarlane, 2007).

RST Research Timeline

ABSTRACT

Hybrid Design Tool Environments (HDTE) allow designers and engineers to use real tangible tools and physical objects and/or artefacts to make and create real-time virtual representations and presentations on-the-fly. Manipulations of the real tangible objects (e.g., real wire mesh, clay, sketches, etc.) are translated into 2-D and/or 3-D digital CAD software and/or virtual instances. The HDTE is equipped with a Loosely Fitted Design Synthesizer (Nxt-LFDS) to support this multi-user interaction and design processing. The current study explores for the first time, the feasibility of using an Nxt-LFDS in a networked immersive multi-participant social virtual reality environment (SVRE). Using Oculus Rift goggles and PC computers at each location linked via Skype, team members physically located in several countries had the illusion of being co-located in a single virtual world, where they used rawshaping technologies (RST) to design a woman's purse in 3-D virtual representations. Hence, the possibility to print the purse out on the spot (i.e. anywhere within the networked loop) with a 2-D or 3-D AM printer. Immersive affordable Virtual Reality (VR) technology (and 3-D AM) are in the process of becoming commercially available and widely used by mainstream consumers, a major development that could transform the collaborative design process. The results of the current feasibility study suggests that designing products may become considerably more individualized within collaborative multi-user settings, less inhibited during the coming 'Diamond Age' (Stephenson, 1995) of VR within collaborative networks and with profound implications for the design (e.g. fashion) and engineering industry. In this chapter we present the proposed system architecture, a collaborative use-case scenario, and preliminary results of the interaction, coordination, cooperation, and communication with immersive VR.

Keywords: collaborative interaction, social networks, hybrid design tool, oculus rift, virtual reality

CHAPTER 9

Hybrid Design Tools in a Social Virtual Reality Using Networked Oculus Rift: A Feasibility Study in Remote Real-Time Interaction

(This chapter is based on the peer-reviewed paper: "Wendrich, R. E. et al. (2016, August). Hybrid Design Tools in a Social Virtual Reality Using Networked Oculus Rift: A Feasibility Study in Remote Real-Time Interaction. In ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers.")

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9.1 On Networks, Social Media and Collaborative Interaction

The ever expanding social media networks, either public or professional, are the driving force behind the rapid growth in interconnected networks. As members of a network communicate with each other they create an interactive network. The growth of such a network has a virtuous or ‘Snowball effect’ (Fig. 134) (opte.org). Every new actor to an established network will increase the number of potential contacts and profitable interactions significantly (Reed, 2001). The potential power of these networks increases exponentially with the number of users.

Many social networks are predominantly formed through informal contacts, often weak connections between people who consult collaborative before determining a view on an issue or choice. When people interact collectively, form opinions, share knowledge or develop activities, the network becomes increasingly more powerful. Often people take part in a number of networks, again these become linked and are mutually reinforcing (Reed, 2001). Gladwell (2001) states that many social networks are dominated by ‘mavens’, people that are often part of more discussion and newsgroups on the Internet and have access to many information sources.

Figure 134. The internet and its exponential growth

Figure 135. Collaborative connected network system

The mavens who are active in a given topic cluster, often have an informal hierarchy, some of them eventually emerge as informal leaders of the group. These people, Gladwell (2001) calls them 'connectors', play a coordination role and maintaining extensive contacts with other social networks. Connectors gather people and play a decisive role in controlling and monitoring network activity. Their reporting can induce others to modify their behaviour. The search for the critical moments that change can bring is just a small step. In this context Gladwell speaks of the '80/20 rule' (Pareto), that indicates that 20 percent of people often determine 80 percent of the decisions (Fig. 135) (Gladwell, 2001). In this feasibility study we connect social-network, VR, and HDTE for remote collaborative design processing and interaction.

9.2 Hybrid Design Tool Environment in Social Virtual Reality Network

The feasibility of using rawshaping in a networked multi-participant social virtual reality environment to remotely teach a new user how to use and interact with the rawshaping interface and hybrid design tool environment (HDTE) Consequently, a design-task is executed with the HDT to iteratively design, generate and create a virtual artefact (i.e. design of a woman's purse). The presented socio-technical system for collaborative learning (e.g. design, engineering, communication), allows multiple users to view, interact, communicate, iterate, and collaborate on the design task in real-time mixed reality (MR). The users have various networked life-feeds and channels (i.e. audio, 2-D visual displays, and 3-D VR headsets) that affords them to choose and decide on-the-fly (real-time) what suits them best in terms of views, presentation and representation.

9.3 System Architecture

Methods used in HDTE setup; using Oculus Rift goggles, Smartphones, Mac and PC computers at each location linked via Skype, four team members physically located in several countries had the illusion of being co-located in a single virtual world, where they used rawshaping technologies to design a woman's purse, and printed out the purse with a 3-D AM printer. The setup employs the Oculus Rift Head Mounted Display (HMD) in conjunction with various skype audio- and video feeds to establish the networked real-time infrastructure. The HMD allows for full immersion, it lets the user view and navigate three-dimensional (3-D) virtual reality environments. The Rift provides high-resolution (960x1080 pixels per eye) stereoscopic images with 100° field of view (FOV).

Figure 136. System architecture diagram

The overall system is comprised of three primary components: visualization using Oculus Rift (OR) for viewing the 3-D environment; the NXt hybrid design tool for iterative design processing; and the Skype communication feeds (i.e. audio, video) (Fig. 136) (Fig. 137). The PC1 contained a 3.4 GHz Core i7 4GB 1 TB CPU and a GTX970 4GB XLR8 Graphics card in order to get the OR running at 60 - 75 frames per second. The other laptops in the VRE-System were standard Mac and PC's equipped with HMD's. On the PC1 and other laptops we installed Virtual Desktop, and Oculus Rift-Runtime for Windows. The visualization and production of live video was done through vMix Live Production software. For the multi-located collaborative user group feeds (i.e. audio and video) we used group-call for Skype. In addition, we used a separate Skype video-feed (i.e. via Smartphone) that streamed the virtual iterative design content generated in New York (NY) simultaneously (very low latency) synchronized with the HDTE tool software (i.e. SWHX) in the Netherlands (NL) (Fig. 138). The iterative content designed and generated by the NY-user (UI-NY) on the NXt were coordinated and facilitated through an audio-cue "Capture," given in NY and actuated (i.e. push on red capture button) by the user in NL (UI-NL) (Fig. 139). The user-interaction between the two interactors appeared to be fluid, in sync, clear in communication, and showed that coordination, cooperation, and collaboration on distance is possible by facilitation of multi-modalities (Fig. 140).

The user located in NY was a first time user of the NXt user-interface (UI) and tool features. She needed very little time to understand, learn how to use, and grasp the workings of the interface, interaction modalities, and system features. This is an indication of the apparent intuitive qualities of the NXt,

by which the user feels at ease and comfortable in using the software capabilities. We noticed some concurrent dislocation constraints during the physical bi-manual interaction and wear of the HMD. Occasionally, users had to move-up the HMD's in order to figure out the exact position/location of the hands in relation to the workspace (Fig. 141).

Figure 137. Setup system infrastructure architecture UT-E-NL

Figure 138. Multiple skype feeds test

Figure 139. Multi-located networked user interaction Olaf Grevnstuk and author with NXt-HDT (foreground) and OR 3-D (background)

Figure 140. Multi-located networked user interaction (on left) OR 3-D goggle view (on right)

Figure 141. *Dislocation constraint HMD during UIA*

9.4 Global Collaborative Learning and Virtualization

Remote real-time collaboration with socio-technical systems and dialogue tools aimed at promoting collaborative learning and deepening the space of debate and producing epistemic interactions is in the interest of designers, engineers and educators around the globe (Baker et al., 2001). This calls for enabling more platforms for real-time collaborations between teams and networks. Design processes can be seen as an integration of a technical, cognitive and social process, and such a process is clearly multidisciplinary (Törlind, 2016). Therefore, it is essential to facilitate global knowledge sharing and communication among individuals and groups. The design and development of collaborative learning systems have had an effect on the emergence of some significant trade-offs related to the means of dialogue, the coordination of action and dialogue, the self-regulation/metacognition of students/users, and the analysis and meta-analysis tools for teachers/industry as well as the differences between 'problem-solving oriented systems' and 'wide community systems' (Dimitracopoulou, 2005). Global virtualized collaborative learning could be viewed as a pedagogical method that can stimulate students/users to discuss information and problems from different perspectives, to elaborate and refine these in order to re-construct and co-construct (new) knowledge or to solve problems. In such situations, externalization, articulation, argumentation, and negotiation of multiple perspectives are considered the main mechanisms that can promote collaborative learning (Dimitracopoulou, 2005), (Dillenbourg et al., 1996). For global industry and manufacturing enterprises, collaborative networks are recognized as a very important instrument for survival of organizations in periods of turbulent socio-economic changes (Camarinha-Matos et al., 2009).

The National Research Council (1998) identified six grand challenges for industry, manufacturers, and education, representing gaps in existing practices:

1. Achieve concurrency in (all) operations.
2. Integrate human and technical resources to enhance workforce performance and satisfaction.
3. “Instantaneously” transform information gathered from a vast array of diverse sources into useful knowledge for making effective decisions.
4. Reduce production waste and product environmental impact to “near zero”.
5. Reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities.
6. Develop innovative manufacturing processes and products with a focus on decreasing dimensional scale.

These challenges require new organizational structures, new educational models and frameworks, new business models, new design, production and management models, new theories, new processes, new socio-technical systems, novel theories and technologies that allow educational systems and industries/companies to face-up to the dynamic and continual oscillating changes evoked by hyper-globalization, hyper-connectivity and hyper-mediation.

9.5 Preliminary Results of Design Task

Figure 142. *NXt GUI and user in action and virtual interaction*

The NXt-LFDS software records all the iterations and virtual instances of the design process, the captured iterations are either saved as individual instances or merged stacks of virtual instances (Wendrich, 2010d). The merged stacks are considered 3-D end results of single or multiple user-interaction. In this collaborative networked design task and setup, the user interaction (Fig. 139, 140, 141, 142) lasted 37 minutes in total; the user made 96 iterative steps with a total of 22 merged stacks (Fig. 143). The results show promise in the use of remote interaction modalities and tool features over long distance with a real-time connected VRE. However, the overall quality and tangible outcome could be debated, the results are interesting enough to share and trigger the imagination and spur the need for more research, testing and experimentation.

Figure 143. *Preliminary raw end results of design task*

9.6 Conclusion

Immersive Virtual Reality technology (and 3-D AM printers) are in the process of becoming commercially available and widely used by mainstream consumers, a major development that could transform the design process. The results of the current feasibility study suggests that designing products may become considerably more individualized and less inhibited during the coming “Diamond Age” (Stephenson, 1995) of virtual reality, with profound implications for the design (e.g. fashion) and engineering industry and manufacturing and production enterprises.

Future Directions; the designer was able to see her hands and the real objects she was manipulating in the NXT-software, via a video feed from a camera pointed at her desk. One disadvantage of immersive (occlusive) VR is that the designer can feel but cannot directly see objects in the real world except through the camera. The designer viewed this as a limitation. A see through augmented reality display (e.g. via Magic Leap or via a head mounted camera on the Oculus Goggles) might work better.

The current version of rawshaping software (i.e. SWHX) is not yet compatible with Oculus Rift Direct Mode. New rawshaping software programmed in Unity will allow a more immersive VR experience. For more information visit vimeo.com, type rawshaping technology for videos on hybrid design tools (HDT), experimentation, testing, blended spaces, user experience (UX), user engagement (UE), user interaction interfaces (IxD), and various other cyber-physical modalities.

'Waar het [ideale type] verwerkelijkt is, heeft gehechtheid aan een exemplaar inderdaad geen zin meer; men houdt alleen van de vorm, niet van het specifieke exemplaar, en heeft ondanks alle kunstmatigheid een eigenaardige nieuwe nabijheid bij dingen(...), namelijk bij de dingen in hun functie'

- Karl Jaspers (1931)

CHAPTER 10

Keep IT Real: On Tools, Emotion, Cognition and Intentionality in Design

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10.1 Creative Thinking and Metacognitive Processing with HDT(E)

In externalizing ideas we feel that it is crucial that you produce as many ideas as possible, produce ideas as raw and wild as possible, build upon each other's ideas and avoid passing judgment (Osborn, 1956). Multimodal interaction with the hybrid machine is to capture as many iterations as possible during design processing (i.e. divergent and convergent) (See also Chapter 2.3 & [Appendix C](#)) whilst simultaneously getting instant virtual feedback from the monitor. Physical two- and three dimensional presentations in e.g. sketches, drawings or low-resolution models made in the process will enrich the process and help to enhance the insight and understanding. Goethe's 'Connect, always connect' seems to be the motto of the designer as, out of the fluid raw material of its experiences, it selects and shapes patterns and relations (Koestler, 1964). Working this way will facilitate knowledge extraction and the creation of possible solutions. The user creates and manifest ideas; externalize thought patterns; makes captures (input) of transformations and manipulations. At the same time when the capture is made the system nudges an output that triggers, distorts, surprises or ruptures the perception and thought process of the user as illustrated in Figure 144.

Figure 144. Creative divergent and convergent processing with the hybrid design tool

Designers or engineers do not necessarily need a computational machine or tool to convey their ideas, fuzzy-notions or imaginations. There is not enough reality in them to justify a sole reliance on digital tools alone; a cross-modality hybrid blend of tools would have much more effect. In order to facilitate a creative environment for play and design in support of ideation and creativity, we just need to be able to explore freely and discover intuitively while thinking-on-your-feet, doing-in-action

and reflection-in-action (Schön, 1983). As Mlodinov (2008) stated that user behaviour is not only unpredictable, but also often irrational, and it is impossible to precisely know and control the circumstances and much is left to chance. The HDT's help to uncover and benefit from these random processes and random user behaviour. The machine progressively nudges towards new iterative steps or transformations to follow up, generate workflow that subsequently results in highly productive creative activity, playful interaction, rich and engaged creative processing. To paraphrase Dalcher (2006) we concur that design is neither orderly nor linear; it implies a continuous and active search to resolve trade-offs and satisfying constraints.

10.2 Enhanced Hybrid Design Tool Environment (eEHDTE)

How can current technology fluidly afford cognitive, emotive, affective, and gesture-based shape and form externalisation in an enhanced Hybrid Design Tool Environment (HDT-E)? Some of the most important aspects and intrinsic to the design and engineering of such ecosystems are:

1. Cognitive: related to knowledge and mental abilities | Aggregating the current knowledge during the process as a result of experiential learning | Supporting decision-making and choice-architecture in later stages by providing overview and understanding of the design process.
2. Emotive: related to subjective, personal experiences | Affective computing; becoming responsive, aware and adaptive to the emotions of the user | Emotional expressivity in the design; the perceived emotions directly influence the externalised representation through, e.g., colour, form details and context.
3. Gesture-based: related to human computer interaction | Human Computer Interaction (HCI) in multiple modalities (multimodal), simply put: finding ways of interacting with the computer that are more intuitive than keyboard and mouse in a 3-D modelling environment | Gestures to control the virtual interaction; e.g. selecting, adding, transforming, morphing, translating and rotating models.
4. Shape and form externalization: related to different types of representation used during the design and/or ideation of a products | Shapes are representations in two dimensions, whereas forms are three-dimensional.
5. Hybrid Design Tool Environment: A design tool that integrates physical and virtual interaction in a contextual environment that supports a designer during the early phases of a design or product creation process.

Guidelines for the HDT in conjunction 3-D sensorial interaction has the following characteristics (Wendrich, 2004), (Kruiper, 2015):

- Tool creates more insight and understanding | 3-D surface data is acquired with the depth camera
- Tool has low threshold in learning curve | Gesture based HCI is one of Kinect's key-features
- Tool increases processing speed in solution space | Optical 3-D scanning, so (near) to real-time interaction is possible
- Tool implies visual and tangible representation | No controller to generate 3-D content, but surface information from interaction with tangibles
- Tool triggers easy ideation and conceptualizing | Quick low-fidelity data acquisition, the accuracy does not exceed the limit of several millimeters

- Tool allows intuitive un-tethered interaction | Most, if not all, non-opaque and non-reflective materials can be used | Besides raw surface measurements, speech and gesture based interaction can be integrated into the HCI of the HDT
- Tool is applicable in a comfortable, contextual surrounding
- Sensing area of the sensor system suits a workbench approach with a sensorial workspace
- Tool and content are portable | The size of the sensor system allows for portability of the HDT
- Cost: COTS products, components, and availability of open source libraries for software development

10.3 Interaction Design (IxD) and User Experience (UX) for HDT(E)

Building on the analysis of our previous research and tool creation, this study integrates knowledge from several fields of research into a broad, contextual direction for the design of HDT's. Generic guidelines for the creation of a HDT(E) are drawn from analysis of experimentation and tool creation. The goal of creating a HDT(E) is to overcome limitations and deficiencies of CAD tools regarding ideation and creative processing in the product creation process (PCP) (Verduijn, 2012), (Wendrich 2009), (Wendrich, 2010), (Wendrich, 2011-2016). In doing so, the interaction design (IxD) is an important aspect that has not been addressed fully yet (Kruiper, 2015). According to Hartson (2010) usability stems "from the effectiveness of cognitive affordances for understanding how to use physical affordances, the physical ease of using the physical affordances, and from the sensing of these via sensory affordances". The usefulness of a system stems from the utility of functional outcomes of user actions. Designing for usability and interaction with interactive technologies is about exploring design spaces, and realizing new systems and devices through co-evolution of activity and artefacts - the task-artefact cycle (Carrol, 2014). The cycle implies that HCI is an ever-changing exploration of new applications and application domains through the co-evolution of activity and (supportive) technological artefacts. This requires the consideration of many alternatives at every point in the progression, if the focus lies too strongly on the affordances of currently embodied technology we are too easily and uncritically accepting constraints that will limit contemporary HCI as well as future trajectories". Hartson (2010) proposed a similar but more detailed IxD model as interaction-cycle mostly based on Norman's (1990) stages-of-action model. Both models consist solely of user-actions, whereas interactive products interpret, process and present information as well. Abowd and Beale (1991) extended the stages-of-action model by adding the system. Figure 145 displays the various models including a proposed integration of an interaction-reflection model; leading to a generic interaction model for the HDT(E) and the cognitive processes that occur. IxD is concerned with "designing interactive products to support the way people communicate and interact in their everyday and working lives" (Rogers et al., 2011). Interactivity is "an expression of the extent that in a given series of communication exchanges, any third (or later) transmission (or message) is related to the degree to which previous exchanges referred to even earlier transmissions" (Rafaeli, 1988). In this definition interactivity is regarded as a user-oriented, uni-dimensional and process-based attribute of a product or system. The goal of IxD can be regarded as the optimisation of user experience (UX), user engagement (UE) and usability in specific, progressing user-context situations through a product's behaviour. This is different from Human-Computer Interaction (HCI), which concerns the design and use of computer technology and focuses particularly on the interface between users and computers (Kruiper, 2015). Interaction with current CAD tools is usually based on interfaces with Windows, Icons, Menus and Pointer (WIMP). Mouse and keyboard are used to perform actions within the virtual 3-D environment.

Jetter et al. (2013) state that research on post-WIMP interfaces are focused on achieving natural and unobtrusive computational support during a variety of activities. The interaction with post-WIMP technologies is usually user-centred and aims to achieve ubiquitous computing environments with ‘invisible’ technology. However, “HCI researchers still do not understand why some post-WIMP designs are perceived as ‘natural’ or ‘intuitive’, while others are not”. Jetter et al. (2013) continues that the latter is due to lack of theory, model or framework about the cognitive processes that let us perceive UIs this way or the other.

Figure 145. HDT(E) generic interaction model, based on integration of existing and proposed interaction models. Green arrows represent how the system might nudge the user to perform certain actions, red arrows represent how a user learns from reflection-in/on-action

Correlating the use of tangible, physical tools and IxD helps understanding the underlying framework of tangibility, physicality, dexterity and embodiment. Spool (2005) states that a design is intuitive if the user does not require new knowledge to operate the system. According to Hurtienne et al. (2007) interaction with a technical system is intuitive “if the users’ unconscious application of prior knowledge leads to effective use”. From this we infer that interaction is considered intuitive when the user is able to operate a system by applying existing knowledge in carrying out intention.

10.3.1 HDT(E) Equipped with Wearable EEG

This wearable user interaction (UI) device (Fig. 146-1) affords to stimulate and facilitate ideation using Brain-Computer-Interfaces (BCI) as an intelligent sensor during the early-phase of a design process

in an intuitive HDT(E). With further development of BCI technology it is possible to gain insight in and understanding of user-aspects yet to be integrated in human-computer-interactions (HCI), such as affective and cognitive states. This plug-and-play interface defines body-signals to provide the user intuitive modalities to execute system actions using facial expressions. The presence of ambiguous elements in using facial expressions, as executer of system tasks, lead to awareness of these expressions, as well as creating experience of the system nudging when these expressions occur unintentionally (Kleine Deters, 2015).

10.3.2 HDT(E) Equipped with Air-Flow-Inter-Face (AFIF)

This AirFlowInterFace (AFIF) device and system allows glassblowing like interaction with a computer, humans have a lot of fidelity with the pressure and airflow (puff and sip) they can exert, so this makes it an interesting input modality for a design process (Fig. 146-2). We developed a Tangible User Interface (TUI) with common off the shelf components that can accurately measure airflow and pressure of a human blowing, and make this data available on a computer for virtual representation and simulation. A graphic user interface (GUI), and visualizer (representation) are facilitated. The wireless handheld device is capable of measuring both human blow pressure and flow rates, simultaneously sends the data values to a receiver that is connected to a PC. It has a 6DOF orientation sensor, so interaction with how the device is held can be created. The combined wireless sensor platform enables users to have new interaction with a PC. Complementary to the hardware we created a software data visualizer that enable data representations to create, e.g. 3-D meshes that can be opened and further iterated in 3-D software suites (e.g. Blender) (Wendrich & Pelt, 2016b).

Figure 146. HDT(E) Tool and interface extensions (1 - 2 - 3 - 4)

10.3.3 HDT(E) Equipped with 3-D Visual Hull Scanner

A low-cost, low-resolution 3-D visual hull scanner (Fig. 146-3) is developed to facilitate near real-time scanning of objects and/or artefacts for integration with a HDT(E). The digitization of 3-D raw objects and low-resolution physical/tangible models during early-phases of design processing to stimulate and generate virtual prototypes or models is crucial during ideation and conceptualization. The application is partly based on the shape-from-silhouette scanner (SFS) (Forbes, 2006) whereby five silhouette images (photos) are used to capture and construct a 3-D virtual model from real-world objects. The device use two off-the-shelf planar mirrors that are positioned to show five views of an object, a LED-backlight surface is used to automate and support the silhouette selection and snapshots are captured from different viewpoints with a HD-video camera. A video camera is chosen to make it possible to generate and make use of live-view feedback during interaction. Silhouette outlines are represented by polygons, and pixels are assumed to be square. The parameters are adjusted automatically to minimise the sum-of-of square distances between epipolar tangencies and corresponding projected tangents using the Levenberg-Marquardt method (Moré, 1978). Each of the five cameras' silhouette views of the real object can be used to compute the five-view visual hull of the object (Forbes, 2006). The average time to generate a 3-D virtual model is about six to thirty seconds depending on the required image resolution levels (Dijk, van, 2015).

10.3.4 HDT(E) Equipped with a Kinect v2

The emotions a user experiences (UX) during HCI with a HDT(E) can be applied in different ways. Three main applications of emotional awareness (AE) and user engagement (UE) have been based on the different processes in HCI: interaction, feedback, or processing. A design process can be augmented through the use of nudge creation, extrapolate emotional awareness, and support emotional feedback (Kruiper, 2015). Besides HCI that adapts to the emotion of a user, monitoring emotional states in a naturalistic setting provides information on the influence of emotional states on the design process and outcome. This could be used to gain insight in the effects of positive affect and flow, the latter being "a state of concentration so focussed that it amounts to absolute absorption in activity" (Csikszentmihalyi, 1990). Flow is a reoccurring phenomenon during several RST experiments (Wendrich, 2014c). Optical 3-D scanning (e.g. Kinect) based on structured light and triangulation, allows for fluid cognitive and gesture-based shape and form externalisation in a HDT(E). Although enhanced interaction might be possible, further research is in progress to determine whether this technology can allow for affective computing. There is no functional prototype as of yet, however incremental use-case studies in conjunction with Kinect setup (Fig. 146-4) have been executed and tested (Wendrich, 2014c), (Kruiper, 2015). This conceptual approach is taken with regards to the Interaction Design (IxD) of a prospective HDT(E) using a Kinect (Fig. 147). The IxD of a HDT(E) is crucial to overcome the deficiencies and limitations of current CAD tools as described by Kosmadoudi et al. (2012). Part of the solution revolves around the application of gamification and integration of tools that afford a large range of interaction styles in physical, virtual and mixed realities. Moded design, as used in the LFDS, and gamification can improve immersiveness while shifting between these realities. Post-WIMP interaction styles, e.g. gesture-based interaction, and sensorial virtualisation (e.g. the puff & sip UI), provide more insight and understanding in the virtual design space than conventional input devices like mouse and keyboard (Kruiper & Wendrich, 2015).

Figure 147. HDT(E) with integrated interaction model equipped with e.g. a Kinect. The system allows for three types of input: analogue, touch and sensorial virtualisation

10.3.5 HDT(E) Equipped with Tangible Pods (TP)

Tangible Pods is a tangible user interface (TUI) that consists of multiple “pods” that form a surface and can be physically manipulated/sculpted to create input data. It is a flexible interface that can be used in a range of applications including music, 2-D and 3-D modelling (Fig. 148).

Figure 148. HDT(E) with integrated TP for Tangible User Interaction

The interface is made for instant creation and self-expression through sound and visuals using computer technology. It facilitates this by giving digital data a haptic manifestation. Similar to a computer mouse a physical action measured by a sensor is interpreted by the computer as input that feeds back to the user; only in this case the interaction is three-dimensional and supports three axes of rotation (six degrees of freedom). Tangible Pods is a hybrid and tactile interface, which makes it more intuitive than traditional WIMP interfaces since the user can rely more on his/her explicit or tacit knowledge of interacting with physical objects. Because of this it can facilitate participation of non-experts in e.g. electronic music making, 3-D object modelling, 2-D and 3-D graphics and visualizations. The current hardware prototype (Fig. 149) makes it feasible to apply and use the IF as a musical instrument/synthesizer in combination with software for music production, creation and performance. Bi-manual and/or bi-footed (Fig. 150) compression of the steel springs serve as tactile feedback platforms. The individual platforms are covered with soft neoprene fabric on top of pressure sensors. Pressure sensors, piezo's and an accelerometer are being used to measure the physical input (I) and an Arduino microcontroller is used to process the resulting input data which can then be output (O) to a variety of music software programs (i.e. MIDI data) (Schaefer, 2016).

Figure 149. *Prototype of TP for Tangible User Interaction (Peter Schaefer)*

Figure 150. *Prototype of TP for Tangible User Interaction*

'Het ligt voor de hand dat elke uitvinding aanvankelijk met scepsis wordt ontvangen. De eerste treinreizen veroorzaakten bij de reizigers oogontstekingen, urinebuisverstoppen en miskramen. Maar vervolgens treedt er een 'stabiliseringsproces' op: de mens past zich aan en incorporeert de nieuwlichterij in zijn leven. In plaats van vervreemding wordt de verandering 'gedomesticeerd'. Technische vernieuwingen zijn een onvervreemdbaar bestanddeel van de algehele condition humaine.'

- Petran Kockelkoren (2003)

CHAPTER 11

Conclusion:

Future Work | Recommendations

11.1 Conclusion

Ideas¹⁴ are hard to find but designers love to have ideas! Having lots of ideas makes a designer look really creative and incredibly talented, which can also make them stand out within their peer group. They are often praised for being so highly creative and smart. They potentially indulge themselves in all kinds of happy thoughts about how good they are and, as a consequence, daydream about having many more ideas in the future. From Polanyi (1966) we understand that tacit knowledge is implicit and inbred; 'we can know more than we can tell.'

We believe anyone can be creative and have the capacity to think of ideas or thoughts that, if implemented, would be so creative and ingenious others could become envious of them. Our hypothesis suggests designers could benefit and gain from externalizing their ideas with the aid of computational machines that would enable creative expression in a harmonized and holistic manner. Sharing and spreading ideas, showing creativity without being inhibited and having confidence to freely convey thoughts no matter how 'ridiculous' they may sound have an immediate effect on a person's behaviour, self-esteem and psychological condition. The cognitive processes of creativity, imagination and inspiration combine well with doing, taking action and being motivated to carry on.

The apparent communication gaps between the human and the machine, is like a gulf of mutual incomprehension. As long as channels for 'communication' remain open and alive the distance between and the differences of the two worlds, are essential to re-conceptualize these fertile but ill-defined contested spaces and realms. According to Truex et al. (1999), ill-structured systems need to be developed using a totally different set of goals that would support emergence, growth and change. Alexander (1964) stated that the main problem often lies in separating activities surrounding analysis and synthesis, rather than recognizing their duality.

According to our research results and findings, the use of tangibles in the early design phase is key to design processing and the development of a HDT(E). In order to use tangibles for physical interaction, the manipulations of these tangibles are to be translated and alternated into real-time representations of a virtual model. Reflection, incubation and learning are encouraged when technology is supportive and calm, it allows user-control, engagement and fosters learning skills while harnessing talent (Wendrich, 2014c) (Wendrich, 2016d). The HDT(E) is a full-loop system, which is used to generate both physical and virtual models. The type of deformations and manipulations on both models depend amongst others on the technology used to acquire data. Our hybrid approach constitutes on the exploration and experimental tradition where we rely on an assortment of heuristics and operate mostly in a highly unpredictable, stochastic and/or probabilistic manner across boundaries and often un-structured approaches. The oscillation between real and virtual realities merges the autonomy of user and machine this will progressively enrich the intuitive user experience, increase knowledge acquisition, and advance insight in understanding.

11.2 Contributions

We accomplished to integrate physical and virtual processing within a mixed reality. We designed, created, authored, and build a wide variety of tools, embodiments, setups and experimental interaction devices that showed lots of merit and promise during processes, user engagement, pleasurable experiences, prospecting expectations, plethora in iterative performances (iteration galore), enhanced

¹⁴ 'Fixed ideas are like a cramp in the foot - the best remedy against it is to tread on it.' - Sven Kierkegaard (1813-1855)

motivation whilst creating enthusiastic users. We tested and experimented with our HDT's in many different domains that supported our assumptions and hypothesis that HDT's are microenvironments that address the needs, wishes and expectations of humanness. HDT's provide comfort zones to support the creative abilities and human capacity to emerge.

Our main contributions can be defined as closing the apparent gap between the human and the machine (i.e. HMI-paradigm) by facilitating e.g., hybrid non-intrusive supportive interface modalities, direct (i.e. real-time) representational feedback loops and robust assistive system environments (i.e. ecosystems) to work in cooperation, semi-immersive and alliance with prospective users. The multi-dimensional aspects and features of our hybrid design tools are perceived so 'life-like' that users experience a semi-immersion and benefit directly from the augmentation during interaction, transformation and real-time visualizations.

The RST workbench approach (posture) aligns with Schön's (1983) 'thinking-on-your-feet' framework, whereby reflection-in-action and reflection-on-action constitutes an important part of interaction, processing and relying on common-sense.

By integrating, blending and merging hard- and software (i.e. hybrid) as a similitude in connection with abstract imaginative representations, we were able to elicit and construe the rawshaping paradigm. Over the years this has led to pleasurable user experiences, enhanced performances, self-affirmation and empowerment. The HDT's assists the users by mimicking the mental process within a virtual solution space, thereby offering tangible support in exploration and manipulation of content.

Furthermore, the HDT's and HDTE's have shown effective, appropriate and useful in various domains whereby the user (-s) directs how the tools are used and control to what extend the tool should be allowed to act as an extension of their physical reach towards a specific purpose. In real-world case studies we witnessed and observed highly-motivated users having virtually no trouble handling and using the HDT's. Our contribution here is the low-threshold in learning-curve, the seemingly intuitive UI's, GUI's, the effective self-explanatory architecture and embodiments of the HDT's.

Timeline, interleaving, feedback-loops and concurrency of our hybrid tools and -systems were considered 'new' functionalities and 'advanced' system modalities within design and engineering tools at the time of conception and realization (2009). Interactive iterative progressions are easy, simple and fluidly traceable and traceback reciprocally affords dynamically controlled continuous workflows. The overall robust interaction design (IxD), user experience (UX) and user engagement (UE) with HDT's and HDTE's are considered inspirational, thought-provoking, highly-creative and 'opened-up' the eyes of many peers and colleagues in the design- and engineering domains.

11.3 Future Work

Future research towards 3-D interaction (IA) with HDT(E)'s is necessary, as well as research into enhanced interaction (IxD) through automatic emotion recognition (AER) and other methods (i.e. sensors, ubiquity, web based) to detect 'creative slowdown', engage user behaviour, foster skill learning and pleasantly nudge during product creation processes. According to Dyck et al. (2003) CAD systems do not have a strategy to communicate between the system and the engineer to enhance the UX and UE. Games on the other hand "...communicate information to users in ways that do not demand the user's attention and do not interrupt the flow of work." McCullough (1996) states, "The possibility of craft lies not so much in the technology as in the outlook you bring to it."

11.4 Recommendations

We recommend to deploy the diversity, richness and variety of HDT's and HDTE's that are based on our defined requirements, specifications and different COTS technologies. The low-cost and high-value strategy allows for the emergence of a large variety of interaction styles, user experiences and serendipitous outcomes. The integration of different tools (i.e. traditional, digital, hybrids) within one cyber physical environment (CPS) can provide a designer with a hybrid workspace that is dedicated to support ideation, creativity and intuition. Familiarity, aesthetics and quiescence in layout and design are an important factor to support these characteristics. Ease-of-use, simple and unobtrusive interfaces that intuit users require appropriate testing and exploration over much iteration of continuously-usable prototypes and agile development. Understanding users and their interactions are matters of approximation, many trade-offs, commonality and should always be founded on humanness.

We have authored, build and tested our prototypes in a variety of embodiments and architectures. All are based on the hybrid approach and underlying framework. Our initial attempt in 2009 to research and develop (R&D) a full-fledged RSFF-HDT system (<https://vimeo.com/43850666>) fell short in terms of realization, robustness, limitations and usability aspects. This was mainly due to the state-of-the-art (SOTA) in processing power (CPU), memory capacity, available hi-end visualization technologies and high costs in acquisition and development in both software and hardware components at the time. Nowadays, the current and future advancements, enabling factors and progressions in technology changed the SOTA at an exponential rate. If we would direct our R&D today towards 'solving the technical problems' we encountered with the RSFF, these efforts would most likely lead towards a successful and fitting solution. However, our latest developments are targeted towards web based applications whereby the interactive modalities are facilitated by smart-sensor devices, goggles, smart-phones/tablets, open source and other effective gadgetry. Based on the aforesaid, we recommend that the next RST developments should be directed towards:

1. Robust web based (i.e. HTML5/CSS3) HDT's (incl. an array of mixed- and augmented sensorial modalities and interfaces).
2. Social-virtual reality networked HDT's (incl. repositories, databases, API's etc.).
3. Real-time web based 2-D and 3-D oscillating RSFF system (incl. 3-D AM process capabilities).

11.5 Contemplation

New, immediate and emergent technologies have caused giant leaps in product use and transformed our daily lives and relations with things and elements massively. In dealings and connections with new pervasive technologies and systems the human persona experiences various stages of cyclic meta-cognitive change in the senses and behavioural aspects. The increase in electronic gadgetry, virtual environments and embedded electronic services continue to surpass the sensorial and usability landscape, leaving a trail of non-adapts and technophobes behind that in some way creates voids and in many cases are difficult or impossible to bridge. The impact and implications of technology on society in e.g. education, business, socio-cultural realities, diversity and environments are enormous and a growing concern. Not only in terms of complexity within existing or renewable eco-systems but also in learning to deal with the lasting change in the human scale. The plethora of daily interactions between people and the hyper-world around them in close mediation and connection with these technology, directs fundamental research to study how to include, actuate and holistically activate people in any of these scenarios.

Intermezzo

"What would really be interesting to see for people, is that beautiful things' grow out of shit. Because nobody ever believes that! Everybody thinks that Beethoven had his string quartets completely in his head that they somehow appeared there and formed in his head. All he had to do is write them down and then they would be kind of manifest to the world. What is so interesting and what really should be a lesson to be learned, is that things come out of nothing, things evolve out of nothing. The tiniest seed in the right situation turns into the most beautiful forest, and then the most promising seed in the wrong situation, turns into nothing. This would be important for people to understand, it gives people confidence in their own lives to know that is how things work. If you walk around with the idea that there are some people who are so gifted, they have these wonderful things in their head, but you are not one of them. You are, sort of a 'normal' person, you could never do all that. Then you live a different kind of life, you could have another kind of life where you can say: 'I know that things come out from nothing very much and start from unpromising beginnings. And I am an unpromising beginning...and I could start something."

- Brian Eno (2002)

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Robert E. Wendrich was born in Meppel, Drenthe, the Netherlands on June 9th, 1955. He studied Product Design Development and Engineering at the Academy of Industrial Design Eindhoven. He graduated in 1983 and emigrated in the same year to Toronto, Ontario and half a year later to Montréal, Québec, Canada. He worked for various multi-national companies in North-America. In 1985 he established his own design and consultancy office Möbius Design in Montréal. In 1992 he moved back to the Netherlands to work for a Dutch design and production company and established in 1995 his own company Intesa Design Inc. in the Netherlands. From 1994 until 2001 he was also part-time design lecturer at the Royal Academy of Arts in The Hague, the Netherlands. He has a number of product design awards and design patents to his name.

Since 2003 he works as assistant-professor and researcher at the University of Twente, the Netherlands. Robert is project founder of Rawshaping Technology (RST) research at the Intuitive Design, Interaction + Simulation Laboratory at University of Twente in the Netherlands. He conducts research on Hybrid Design Tools at the Faculty of Engineering Technology at the University of Twente. He was awarded the Best Teacher Award from the Faculty D&E in 2005 and 2007 and nominated in 2011 and 2016. In 2006 he earned second place Central Teaching Award at the University of Twente. He is a member of EuroVR VETE SIG, Emotional Engineering SIG, Design Society (DS), and American Society of Mechanical Engineers (ASME). In the past five years he has received a number of awards for his Hybrid Design Tools and HCI-systems.

'The reasonable man adapts himself to the world: the unreasonable one persists in trying to adapt the world to himself. Therefore, all progress depends on the unreasonable man.' - G.B. Shaw (1903)

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APPENDICES

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Appendix A

Listing and explanation of RST Experimentation

Table Experiments (experiments with the LFDS are blue)

#, Year	Experiment	Goal	Description	Conclusions
#1-#7, 2009 [1][2][3][4]	Seven representational design experiments	Investigation on the influence of various representational techniques on design processing, unleash intuition, and the realisation of designer's intent.	Seven test benches are used for experiments on design representations. Participants are handed an orthogonal projection of an automotive design icon. Using the different test benches they have to make a 3-D representation of the automotive design icon. The time limit is five minutes. <i>The seven test benches are:</i> Expt. 1 – Pencil sketching Expt. 2 – Sand sketching Expt. 3 – Steam sketching Expt. 4 – Plying wire Expt. 5 - Sculpting Expt. 6 - Solid modelling Expt. 7 - Virtual Clay modelling	<ul style="list-style-type: none">• The results show that tangible interaction has merit. Especially untethered two-handed interaction, because it speeds up interaction, lowers threshold in learning curve and stimulates flow and engagement.• Increasing complexity in representational techniques relates to a less detailed representation. Whereas less demanding interfaces steam up the pace and create flow in interaction.• Natural interaction provides direct feedback and more insight in shape, spatiality and problem solution.• The use of digital devices and the use of a force-feedback device proved to be not effective and some participants gave up or

#8, 2009 [1][3] [4]	Design an automotive artefact	Investigation of insight in scale, proportion, global and detailed shape and form during the translation and transformation from 2-D to 2-D and 2-D to 3-D.	Participants are handed an orthogonal projection of an automotive design icon on A4. They have to enlarge the drawings to an exact dimension of 488x180x147mm. They have to use the enlarged projection to create and construct manually three 3-D wire frames: one of aluminium wires, one of cardboard strips, and one of sheet metal strips.	<p>Participants became frustrated with their results.</p> <ul style="list-style-type: none">• Participants find it difficult to interpret the scale, proportions, dimensions and sometimes details.• Design processes with less attention for detail result in a lack of proportional understanding• Analysis of the results showed that by randomness, ambiguity and creative tinkering was synthesized into a huge array of different interpretations of the model.• Freedom in creation in a practical learning context allowed the occurrence flow, passion, idiosyncrasy and autonomy in the design process.
#9 2010 [4][5]	Blindfolded haptic interaction	Measure, explore and quantify the effectiveness of tacit and	Blindfolded participants were given either in-ear spoken instructions, or tangible instructions in recreating an automotive artefact. In the first case the participant was handed a 2-D wire frame of	<ul style="list-style-type: none">• Tangible feedback forms an essential part of understanding shape, enhances distributed

#10 2010 [5]	Cave mimic interaction	1) Observation of user interaction and representati on skills with various tangible materials, constrained by a time limit. 2) Observation of the effects without and with face-to-	tangible knowing without visual clues.	the artefact to function as a size constraint and a set of wheels. In the latter case the participant was handed a 3-D scale model of the car. By using solely haptic perception, in both cases aided by the variant instructions, the participants had to identify, recognize, re-create, mimic and sculpt a 3-D representation of the shape in clay.	<p>cognition and supports intuitive interaction.</p> <ul style="list-style-type: none"> Participants immerse in an explorative design process as they rely on primarily haptic perception to identify, recognize, re-create, mimic and make a 3-D representation of shape.
				<p>In this haptic experiment participants were standing at workbenches in a cave-setup, separated from each other by a sliding door. One participant was handed a 3-D scale model of a car, the other participant a wire outline (2-D) and a set of pictures of a car. Both participants had to shape, construct and transform ten car model iterations during ten minutes with a variety of materials.(i.e. rope, paper, tape, wire, cardboard etc.)</p> <p>The first five minutes individually, after five minutes the sliding door would open and the participants could collaboratively interact and communicate for another five minutes to make various iterations (iteration galore)</p>	<ul style="list-style-type: none"> Sequential progression stimulates the creative process. Short iterative sprints result in a richer choice-architecture in the overall design process, which benefits the quality of the results. The presented role-models largely directed the design process of the participants during the first five minutes. The participants given the wire outline for example created mainly 2-D representations. After opening the sliding door, the iterations moved towards a

		face interaction, mimic, representation, and communication.		<p>3D representation. The participants changed their approach to modelling and use of materials, based on shared information (i.e. visual clues, mimic problem solutions).</p> <ul style="list-style-type: none"> Participants that used the role models more obviously by holding them frequently were more precise in following symbolic form and level of detail.
#11 2011 [6]	Individual window pane morphing with eye-tracking and simultaneous collaborative window pane morphing.	What is a participant's focal point during artefact perception and does this change during a morphing process of two artefacts?	<p>In the initial setup two participants had the task to draw a step-by-step morphing process between pictures of two artefacts. The morphing task was either based on 1 participant (slave) reacting on the sketching of the other participant (master), or based on both participants sketching simultaneously (master-master variant).</p> <p>In a later setup, individual participants had to perform the same task while the eyes of the participant were being tracked. The eye-tracking information shows the focal point in relation to process-overview.</p>	<ul style="list-style-type: none"> Participants have the habit to follow instructions rather than interpreting the goal of the task. In the individual setup the sketches were mostly 2-D, even though the artefacts were all real 3-D objects. Participants do not pay attention to proportions and scale during a morphing process. An overall lack of

			Real artefacts were used instead of pictures. In an in-depth study on artefact perception, participants from different educational backgrounds were asked to look at an artefact while their eyes were being tracked.	<p>detail was noticed, even though the participants looked at the artefact many times per iteration: <i>The eyes of the participants focussed back and forth between the target artefact, the last iteration and the current sketch. For every iteration, the eyes shifted between ± 30 and ± 50 times.</i></p> <ul style="list-style-type: none"> • Uncommon features drew the visual attention on different parts of an artefact in the setups with eye-tracking. These features differentiated from the rest due to: colour, shape and contrast.
#12 2011 [6]	Collaborative window pane sketching and mimic with and without eye-tracking.	Observe face-to-face interaction and collaboration of participants while sketching in the same workspace	Two participants standing each on one side of a windowpane were asked to draw on the pane. The participants were given two markers with a different colour. The participants were given the task to create a scene together (e.g. a planetary system). Given the task, communication was essential. The timeframe per experiment was 3 minutes, as this would stimulate the emergence of flow [LEENDERT].	<ul style="list-style-type: none"> • Collaboration between participants leads to an action-reaction pattern. As one participant is sketching, the other participant tends to observe his/her actions. • The participants take a step back to gain overview on the process, the visual attention is divided over empty spots

				<p>In a second setup, one of the participants wears an eye-tracker. The task and the experimental setup does not change.</p>	<p>and the drawings of both participants.</p> <ul style="list-style-type: none">• Simultaneous sketching occurred as well, although the participants would use a different area on the pane.• The eye-tracked participants check how the other participant reacts on their sketches and iterations.
#13 2011 [7] [10]	Custom Value Engineering	Investigation of interaction and communication between various stakeholders engaged in a hybrid design environment.	<p>This experiment was conducted in collaboration with ProRail BV in Utrecht, the Netherlands. Testing and experimentation was done with the Loosely Fitted Design Synthesizer (LFDS). Twelve participants (stakeholders) and four researchers were present during one session. Firstly, the stakeholders were divided in two groups, working at their own LFDS system. Secondly, the groups were joined to work together at one LFDS workbench. A facilitator gave instructions, as the participants had no former experience with the LFDS.</p> <p>The task was to reach commitment and understanding between all stakeholder involved in the re-design, construction and development of the train-station in Alkmaar (NL). More specifically the design</p>	<p>Participants emerged in an intuitive process, acting out of natural intention and capturing results in close cooperation with other group members.</p> <p>The LFDS formed a focal point, supporting engagement of all users, resulting in cooperation and liveliness. The task-space became a subspace of the communication space, where the addition of annotations and comments by various participants benefitted the outcome.</p> <p>During the second part of the session, the participants in</p>	

			and construction phase of a passage way and a bicycle storage facility. The participants could use various traditional tools, maps, artist impressions and photos of the site.	<ul style="list-style-type: none">the combined group started to elaborate more on their viewpoints.The participants pointed out that the LFDS supported decision-making based on knowledge presented throughout the entire session.
#14 2012 [8][9] [10] [11]	Individual and collaborative	Investigate the difference between individual and collaborative PCP in a Hybrid Design Tool Environment (HDTE).	<p>Participants had to work individually or in groups of two. The design environment consisted of a traditional design workbook and the LFDS. None of the participants had former experience with the LFDS.</p> <p>The individual participants were given the task to design a concept for a handheld mixer. The participants had thirty minutes to complete the task. The participants were handed a DC motor and power cord with plugs as core-functional elements (metaphors).</p> <p>The collaborative participants had a 45 minutes time-limit to design a computer tablet. Five metaphorical artefacts were handed to the groups as predetermined parametric and physical constraints</p>	<ul style="list-style-type: none">VIA (video interaction analysis) showed high levels of performance, motivation and intentional interaction during the design processes.Simultaneous representation, negotiation and reflection-in-action during collaborative design processes show the effectiveness and efficiency of tangible representation.Participants indicated being stimulated by the multi-modality and physical aspects of the design process in a HDTE. Their perception of time and engagement with the design process clearly indicates signs of flow.

#15 2013 [11] [12]	Collaborative Multimodal Automotive Artefact Design	Investigate multi-modal creativity and ideation processing in a collaborative e-individual design task.	<p>Bachelor students without any experience with the LFDS were paired in 38 groups of two. Each group was given some simple 2-D line-drawings of wheels to trigger their imagination. The participants had the task to create a collaborative representation of an 'automotive design' in five minutes time. Using the LFDS, they could shape, sketch, visualize and represent ideas based on individual and/or collaborative choices and actions. After the experiment, the participants had to iterate on their design representations individually.</p>	<ul style="list-style-type: none">• The participants create iterations both individually and together as a result of communication and collaborative reflection-in-action. Collaborative deliberation and reflection-on-action occurs and directs outcome.• A facilitator enhances interaction and amount of output, as first-time users tend to forget to capture iterations during the process.• The LFDS supports a high iteration speed, which is beneficial for the collaborative creativity and ideation.• The use of an inspirational set of LFDS outcomes for the second part of the task resulted in more daring and creative designs. Between group members a clear difference in idiosyncratic style and imagination was visible.
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#16 2014 [13]	Comparison of tools in early phase design processing	See whether a correlation exists between ease of tool use, tool performance, tool satisfaction, tool expectations and former experience	<p>Three separate collaborative design tasks based on the same problem definition were handed out on two different dates. The participants had to design and ideate a hydrogen car using predetermined constraints of functional elements and making as much iterations as possible in 10 minutes.</p> <p>Groups of two students had to perform this task in one of three setups. Participants had to perform the task and used traditional design tools (paper, markers, pencils etc.), digital design tools (laptop, CAD software, tablet etc.) or hybrid design tools (LFDS). Facilitators gave instructions and at the end of the session the participants filled out a questionnaire with question that ranged from user experience; user interaction; ease of use; productivity; user satisfaction; exploration; user performance; user progression; expectation; and successful output.</p>	<p>Only preliminary findings and results yet:</p> <ul style="list-style-type: none"> Participants using the hybrid tools were more motivated and focussed on the design task. Overall the usage of digital tools was thought to be harder, slower, less satisfying and did not meet user expectations. Participants using the hybrid tool agreed that the interface was pleasant to work with and found it easy to explore the system by trial and error.
#17 2015 [14] [15]	Pairwise Comparison of Hybrid Design Tools	See whether a correlation exists and/or IxD comparison can be made between	<p>Two hybrid design tools (i.e. LFDS & NxtLFDS) are used to test and explore the user interface (one analogue/one touch-based) in conjunction with a collaborative design task based on the same problem definition. The participants had to design and ideate a hydrogen car using</p>	<p>Only preliminary findings and results yet:</p> <ul style="list-style-type: none"> Participants using the hybrid tools were more motivated and focussed on the design task.

		<p>ease of tool use (UI), tool performance, tool satisfaction, user engagement (UE), tool expectations and user experience (UX) with two HDT embodiments.</p>	<p>predetermined constraints of functional elements and making as much iterations as possible in 10 minutes.</p> <p>Groups of two students had to perform this task in one of three setups. Participants had to perform the task and used traditional design tools (paper, markers, pencils etc.), digital design tools (laptop, CAD software, tablet etc.) or hybrid design tools (LFDS). Facilitators gave instructions and at the end of the session the participants filled out a questionnaire with question that ranged from user experience; user interaction; ease of use; productivity; user satisfaction; exploration; user performance; user progression; expectation; and successful output.</p>	<ul style="list-style-type: none">• Overall the usage of digital tools was thought to be harder, slower, less satisfying and did not meet user expectations.• Participants using the hybrid tool agreed that the interface was pleasant to work with and found it easy to explore the system by trial and errors.
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Appendix B

Qualitative Data Analysis (QDA) on RST Experiments:

Overview of keywords and the relationships between them - All Experiments

Overview of keywords and the relationships between them per Experiment

Overview of keywords and the relationships between them of Pre- and Post-LFDS

Appendix C

What are Blindspots?

Blindspots (Wendrich & D'Cruz, 2011) are unexpected, unseen, unknown, unforeseen and/or ignored areas of knowledge or gaps in understanding and experience in the world around you. They are a combination of low predictability and large impact once they become apparent.

Blindspot Concept

Engineering education has been noted for its lack of appreciation for and adoption of the findings of education research and education psychology. This project will establish an evidence-based model for supporting creative design teaching that will provide the pedagogical basis for the development of the BlindSpot Workbench (BSW), enhancing engineering and design education. Our aim is to enable engineering instructors to address the blindspots in engineering design education through the provision of an easily adoptable multi-modal workbench, which will nurture students' creativity and enhance their innovation capacity. In general, engineering graduates are not conscious of user requirements, experiences or attitudes and of their importance in design. Engineering curricula do not typically encourage or reward risk taking, non-linear approaches and experimentation, all of which are reported to develop creativity and innovation. Engineering education generally lacks encouragement of cycles of divergent and convergent thinking, reflection and incubation that are cited as promoting and developing creativity.

Rationale - What are the main ideas that led to the proposal of this work?

The idea of BlindSpot emanates from the research and education in design and mechanical engineering at the University of Twente by Prof. Wendrich. In meetings and discussions with other scientists (i.e. conferences, networks) it was concluded that 'blindspots' are systemic issues and apparent in many other domains. In reviewing research literature for blind-spot problems in the design and engineering domain, we came across a large variety of topics and numerous references that address these issues. Many different approaches and perspectives acknowledge the different aspects of blind spots often postulating possible solutions or proposing methods that point to new problem-solving directions or the creation of new paradigms. Newell (1990) notes that there is a phenomenon analogous to convergent evolution in engineering: entirely independent design teams come up with virtually the same solution to a design problem. This is not surprising, and is even highly predictable, the more constraints there are, and the better specified the task is. If you were to ask five different design teams to design a wooden bridge to span a particular gorge and be capable of bearing a particular maximum load it is to be expected that the independently conceived designs would be very similar - for the efficient ways of exploiting the strengths and weaknesses of wood are well known and limited. Furthermore, looking at blindspots from another perspective, Ramachandran (1985) and others (e.g., Hofstadter- see Dennett, 1987) were soon to point out that Marr's top-down vision has its own blind-spot: it over-idealizes the design problem by presupposing that first one could specify the function of vision (or of some other capacity of the brain) and second that this function was optimally executed by the machinery.

Early adoption of basic blind-spot awareness and gradually evolving this to address more complex blindspots within educational curricula will invoke insight in understanding these issues early in

the learning and knowledge gathering process. Using computational tools in conjunction with common-sense approaches and hands-on experiences will define the BlindSpot project rationale, to ensure fostering creativity in learning processes. Drucker (2009) argues unless scholars in the humanities help design and model the environments in which they will work, they will not be able to use them. Tools developed for PlayStation and PowerPoint, Word, and Excel will be as appropriate to our intellectual labours as a Playskool workbench is to the chores of a real plumber. The analogy here is that Prof. Wendrich once bought a very beautiful portable Olivetti typewriter because an artist friend of his said it was so elegantly designed and that it had been immediately put into the Museum of Modern Art collection. The problem? It wasn't designed for typing. Any keyboardist with any skill at all constantly clogged its keys. A thing of beauty no doubt but it was a pain forever. He finally threw it from the fourth-floor tower of Wurster Hall at the University of California at Berkeley, as it didn't enable him to complete the activities it was supposedly designed for. The Cox review in the UK (Cox Review of Creativity in Business, 2005) equally addressed the issue of development of creative skills and the associated impact this would have on economic success. Both this review and the Report of the Innovation Task Force in Ireland (2011) highlight the importance of the ability of graduates to be able to work across disciplinary boundaries and effectively with other specialists. Interestingly the Cox review defines creativity as 'the generation of new ideas', innovation as 'the successful exploitation of new ideas' and design is described as 'what links creativity and innovation'. Design is a key component of engineering education and has been identified as providing an opportunity for developing creativity (Petty 1983, Charyton et al. 2008, Wong and Siu 2011). The identified problem of the blind-spot in education and industry is not a regional or national issue nor are they specific to a particular area or domain. We have to recognize the fact that humans, well-educated or non-educated, have blindspots, and that this has far reaching and extended universal implications. Tackling this issue within the education realm on a trans-national basis and scope will raise awareness and consciousness. Addressing blindspots brings to mind that we have to respect and foster socio-cultural perspectives as a challenge and opportunity to stimulate diversity, accept differences and allow alternative views or perspectives on a variety of subjects and issues. BlindSpot helps to define on an international level how we can help, assist and support future designers and engineers to work and prosper in a constantly changing networked society, workplace and future world. Creativity has seen a surge of interest in education in recent years and this, combined with an increased emphasis on creativity in society, has been met by educators as a positive move (Craft, 2003/2007). Current learning and education methods and curricula are often not up to par with current trends, state-of-the-art developments and societal change in human interaction, technology and communication. The fit or mismatch with industry (SME's) concurrently has major implications on both sides of the spectrum. In turn this could lead to knowingly or unknowingly creating gaps or voids in transfer of knowledge, experience and professional mismatch in both education and industry and vice versa. Furthermore, employers now require their workforce to be able to be flexible, innovative, strong communicators and be able to work as part of a team (NACCCE, 1999). BlindSpot requires a continuum where technology and tools are needed to assist us in the process of magnifying and de-magnifying of the problems, challenges and issues at stake and acquiring an a space satellite view (bird's eye view analogy) and a nano-tube introspection of them. European research and development in the area of blindspots in design and engineering is an overlooked domain, however necessary and urgently needed. In order to adapt, alter and/or change education curricula to create awareness in education and industry for the BlindSpot continuum it is imperative to embed non-linear, non-standard thinking in the forming of new curricula, policy and strategy to formulate a more imaginative and creative

approach to learning and education. Technology and computational tools should be an intrinsic part of this along with a more human-centred approach by placing humans-in-the-loop or on-the-loop. Both will have a strong impact on behaviour, learning, skills and experience with a strong directive on intuition, ingenuity and innovation. It is a priority to make more adaptive learning environments in educational institutions based on pleasurable engagement, enjoyment, serious gaming and play to ignite and foster creativity. Creativity has seen a surge of interest in education in recent years and this, combined with an increased emphasis on creativity in society, has been met by educators as a positive move (Craft, 2006). Engineering education has been described as traditional in its approach. In spite of the advances in information and communication technologies (ICT) which have been made in recent years, engineering education is still delivered in the same way as it has been for decades (Vest, 2005). Most teaching and learning is strongly fixed on old-school ideologies and methodologies, following a pre-meditated linear approach to knowledge-dumping, top-down tutoring, knowledge-testing and quantifying results. The foregoing combined with i.e. programmer's direction in tools, cumbersome interfaces, high-threshold learning tools and applications in learning models tend to create latency, irritation, de-motivation, and apathy. Colwell (2005) states, if engineers only had to follow a set of directions, we wouldn't need engineers; computers and robots can do that much. The real art of engineering, its sine qua non, is in evaluating a proposed design from every angle and vantage point to make sure a design will achieve its goals and prove reliable over its intended lifespan. Again, these notions apply to the education as well as the real-world working domain. The challenge is to research and develop calm and ubiquitous technologies and computational tools that assist and support human-interaction and communication. This is what the BlindSpot will undertake.

BlindSpot Solution

Engineering education has not embraced the findings of education research and education psychology (Felder et al., 2000). The National Academy of Engineering (2005) recommended that, in addition to technical excellence, engineering graduates should, through their education, develop strong analytical, communication and problem solving skills, that they should become creative and innovative and that they should develop the skills to become lifelong learners. Engineering design education is the focus of this project and is being used as the vehicle within the curriculum that has the potential to unlock the creative abilities of students. The key area of design teaching within the engineering curriculum in higher education is the main focus of the BlindSpot. Changes in the approach to design teaching could have a significant impact on the development of the key skills which have been classed as vital for the engineer of the future; creative skills, innovation skills, communication skills; team-working skills and the ability to work across disciplinary boundaries. The challenge to address is that of unlocking the creative potential of students in an exciting and engaging way through the development of an evidence-based model and multi-modal ICT based tool, named the BlindSpot Workbench (BSW). The focus will be on the 'blindspots', for example in working with a multi-disciplinary team. Mackay (2003) states the following; "Someone trained exclusively in one of the necessary disciplines is likely to interpret the design problem from within the framework of that discipline. This causes problems when people from different disciplines use the same words to mean different things or use different words to mean the same thing". This BlindSpot scenario is illustrated below in Figure 1:

Figure 1. Interaction design requires input from sciences, engineering and design disciplines. (Source: Mackay, 2003)

Blindspots (Fig. 2) are the things you do not (yet) know, know or feel. By being made aware of the existence of your own and other's blindspots it can then be effectively accessed and used for creative problem solving and idea generation.

BlindSpot Process

Figure 2. The Concept for the BlindSpot Triad

Appreciating and tackling blindspots head-on early in the ideation and conceptualization stage empowers the designer to produce more creative, effective and appropriate designs. This can greatly reduce product development time, costs, fast-track release to the marketplace and enhance success.

BlindSpot Objectives

BlindSpot aims to provide measures and to meet the following objectives as specified in EU call:

Primary

d) Computational tools fostering creativity in learning processes: innovative tools encouraging nonlinear, non-standard thinking and problem-solving, as well as the exploration and generation of new knowledge, ideas and concepts, or new associations between existing ideas or concepts. The aim is to support people's learning as well as the formation and evolution of creative teams by developing technological solutions that facilitate questioning and challenging, foster imaginative thinking, widen the perspectives and make purposeful connections with people and their ideas.

Secondary

a) Technology Enhanced Learning systems endowed with the capabilities of human tutors. Research should advance systems' capabilities to react to learners' abilities and difficulties, and provide systematic feedback based on innovative ways of interpreting the user's responses - particularly in relation to deep/shallow reasoning and thinking. Research should advance systems' understanding and use of the appropriate triggers (praise, constructive comments, etc.) influencing learning. The systems shall improve learners' metacognitive skills, understand and exploit the underlying drivers of their learning behaviours. Solutions should exploit advances in natural language interaction techniques (dialogues), in rich and effective user interfaces and should have a pedagogically sound, smart and personalized instructional design.

We detail how we meet these in the project objectives below. The BlindSpot project aims to improve engineering education in these early phases by:

1. **Providing greater understanding as to the opportunities and limitations for nurturing creativity and improving creative potential within higher education by defining relevant scenarios** through a participatory design approach with students and educators in 5 European Universities from the Netherlands, UK, Ireland and Greece
2. Critically reviewing the current literature and best practices for evoking creativity in order to define appropriate learning models for engineering education and define the **BlindSpot model for creativity in engineering education**
3. **Defining the BlindSpot framework**, which will consider the requirements of the 5 partner universities (UT, UNott, DMU, UCD, ICCS), and select the appropriate methods and tools for the implementation of the BlindSpot model
4. **Developing, integrating and implementing the technical concepts** into the BlindSpot Workbench, which will facilitate the delivery of the BlindSpot model
5. **Evaluating and validating all BlindSpot concepts** - framework, model, workbench - for their effectiveness and develop new metrics for evaluating creativity
6. **Disseminating and exploiting all outputs by the consortium partners** including the results of project work undertaken by the engineering students in all 5 partner university workshops as well as the models, methods and tools produced.

The expected outcomes are as described in the following subsections.

Scenarios for Nurturing Creativity and Creative Potential in Design and Engineering Education

Within the engineering curriculum design has been highlighted as the key area providing opportunity for developing creativity (Petty, 1983; Charyton et al., 2008; Wong and Siu 2011). The use of open-ended problem scenarios in design teaching is highlighted as important in developing creativity and providing authenticity to the design experience (Rugarcia et al., 2000; Silva et al., 2009 Page and Murty, 1990). Teamwork/groupwork activities are also cited as important in the development of creativity (Silva et al., 2009; Chan et al., 2005; Wong and Siu, 2011) and these have been shown to lead to enhanced academic achievement (Springer et al., 1999). Development of creative and innovative potential has been linked to exposure to, and development of attitude towards, risk taking (Garavan and O'Kinneide, 1994; McWilliams and Haukka, 2008). The development of both divergent and convergent thinking at points within the design process have been linked with creative engineering design (Charyton et al., 2008) and it has been noted that divergent thinking is not encouraged within engineering education (Törnkvist, 1990). Murray and Renton (1988) highlight the importance of awareness of user-requirements and attitudes within design teaching. The combination of technology, business and user requirements within design must be understood by engineering students. BlindSpot will investigate in the 5 partner Universities where, when and how changes in education approaches could be implemented to support students and educators in developing creative potential.

BlindSpot Model for Creativity

There are many differing views regarding the concept and effectiveness of teaching creativity, however there is agreement in the literature regarding the need to nurture creativity and improve creative potential (Chan et al., 2005; Badhran, 2007; McWilliam and Haukka, 2008). The concept of active learning with a learner-centred approach is highlighted by many as an effective method for preparing engineering students to be adaptable and ready for their future careers (Baillie and Walker, 1998; Blashki et al., 2007). BlindSpot will consider the main approaches to creativity in design and engineering education (for example, group/team-based activities, exposure to and encouragement of risk taking, and divergent as well as convergent thinking) in order to establish the appropriate learning methods to be used within the project. The research into creative approaches and learning models will identify a theoretically grounded set of conditions that facilitate and encourage creative design. Building on this foundation a defined design process cycle will provide the scaffolding for the model which will support creative design teaching and learning within engineering design education.

BlindSpot Multi-Modal Workbench

The multi-modal BlindSpot Workbench (BSW) is a holistic mixture between analogue and digital realms, experiences and realities. The BSW environment supports physical and virtual interaction coupled with a variety of interconnected physical and virtual interfaces. The individual user(s) work within a collaborative workbench setting to stimulate face-to-face interaction, visual representation, utterance and verbal communication. Direct physical and tactile manipulation of real-world-objects, artefacts, materials and tools immerse the users in the task representation. A variety of Clients (plug-ins) support and assist the users during interaction in enhancing the representation, presentation and simulation through e.g. Tablets, Capture devices, Audio support, Motion tracking, Augmented Reality and Virtual Simulation. The role of the tutor evolves to facilitation, for monitoring and authoring the

activities within the specific learning task and/or scenarios. The BSW is all about choosing your tools wisely, fitting the purpose, feeling comfortable, engaging and enhancing the experience. The BSW should not inhibit creativity by high threshold in usage or learning curve, instead it should convey new experiences, open-up new routes, stimulate collaboration, risk taking, and induce enjoyment in active learning and making mistakes. The BSW should also offer users the ability to create custom multi-modal tools, interaction metaphors, creative methods, etc., that can be re-used in further sessions, allowing the more experienced user to better exploit the potentials of the BSW itself. The objective of BSW is to create an engaging environment where the users can make a difference and feel in control. The BSW will unleash creativity and innovation by recognizing that individuals are the ultimate source of value. The BSW intuitively assists the user to engage and immerse themselves in interaction and representation. The BSW system supports superfluous interactions in a multi-modal synthetic environment. In the event of starting a specific design task or design processing assignment based on a scenario or case, the user will formulate and sketch some initial thoughts or fuzzy notions using for example pencils, pens, markers and paper on a tabletop (physical representation) simultaneously they activate the BSW (virtual representation) and input the design target and initial rough thought compositions, models or visual ideas. The BS main client assists the user on its way to dynamically participate in the design process by actively supporting the interaction with e.g. loosely-fitted representation, active cues, feedback etc. The basic data will be fed into the BSW system with aid of the BS client by means of a graphically appealing intuitive user-interface incorporating various modalities and functionalities. The tutor holding the BS Tutor client follows the processing of the user, insert fitting and unexpected cues, questions, remarks to stimulate thinking-in-interaction, doing-in-action and enthuse the user interaction. Varieties of gestures or dynamic aspects of the interaction can be visualized with plug-in clients (e.g. haptic device, exoskeleton, tracking device) and will be input into the BS system and represented by simulation on the BSW client. Translation of dynamics or gestures will be two- or three-dimensional object oriented representation and a combination of mixed realities. The output could be in two- or three-dimensional animations, visualization or multi-media representations. Figure 3 shows this system concept.

Figure 3. The Concept for BSW

The system architecture and software technologies of the BSW are based on Client- Server- Storage protocols working with three interrelated and connected tiers - forming the Interaction, Application and Computation domains.

The Client Tier (user interaction) interacts with Mixed Reality applications, interfaces, modules, and /or plug-ins through the Local BlindSpot Server (LBSS). This is the representation, presentation, rendering and simulation side to support the creativity in user-interaction. The Logic Tier handles all the data, analysis and visualization by means of a Local Data server on the LBSS. In the back end of the system architecture a Collective Sharing Server (CSS) is part of the Data Tier. Network connectivity is established locally through WLAN (Wi-Fi) and syncs data via the Web (Cloud) to the CSS. The interaction between users and applications remains uninterrupted, continuous and fluid, thanks to the WLAN connection, while the sync with the Data Tier is done through a web connection, which ensures flexibility and accessibility.

The BSW will support different delivery/usage methods/levels (see also Fig. 4):

- Level 0: BlindSpot Workbench (any tabletop will do) for the starting or preparation of processing with analogue tools and physical materials, artefacts or objects. To ignite and trigger imagination and creative thinking.(physical representation)
- Level 1: BlindSpot Client (interface, basic capturing, creative process walk through, BlindSpot cues)
- Level 2: BlindSpot Client + BlindSpot Server, (storing / serving media files, collaboration with multiple clients, tutor client for facilitation and BlindSpot cues)
- Level 3: BlindSpot Client + BlindSpot Server + Plug-in Clients (Full potential, extended capturing, plug-in client > server > BlindSpot > client)

Figure 4. The concept of BSW usage/delivery methods/levels

These are the functionalities of the different elements within the BSW (see also Fig. 5):

- BlindSpot Client. Main BlindSpot Android Tablet or SmartPad (Apart from the physical workspace this BSC will be the main interface for HCI and basic virtual representation).
- BlindSpot Server. Media/data server, storing/server processes and media files, supporting collaboration (next level of HCI and enhanced virtual representation).
- Plug-in Clients. Separate clients that provide extended capturing (e.g. exoskeleton, sound, tracking) (top-level of HCI and extended virtual representation and tangible and audible feedback from simulation and representation).

System Architecture

Figure 5. The Conceptual BSW system architecture

Progress Beyond the State-of-the-Art

Crucial steps for Progression in Design and Engineering Education

BlindSpot research and development will aim for the essential advance in technology as a crucial step towards radically new forms and uses of computational tools for learning. BlindSpot will incorporate distributed computing and assimilation of open-source applications, implementation of information technologies within a clear long-term vision that is far beyond the state of the art. With respect to the design and engineering domain we focus on, a main aspect is the embedding of design in life. Therefore we need to reduce complexity, keep technology simple, highly-effective and find a balance between objectives, expected audiences and anticipated outcomes. With the aid and inherent possibilities of, i.e. Web 2.0 (e.g. crowd, cloud), we have to push the limits of life-long learning without the feeling of tradition and history, but with an open mind and free expression.

We need to stimulate meta-cognition, meaning feeling the love to make things with your hands, upskill your tacit tangible talents, trigger insatiable curiosity, and manifest in a highly unorthodox

creative way. Creativity needs space, inspiring atmospheres, pleasurable realms, places for reflection and informal environments to come alive. The BlindSpot project will steer beyond the now towards the foreseeable future departing from re-doing the past. Presently education and learning are soaked, drenched and infected with standardized uniform and ready-made methods marginalizing and stagnating creativity. Industry often has no better solutions and follows suit. BlindSpot will not conform but will progress to be stimulating and exciting in Human-Computer-Learning-Interaction. BlindSpot will have a profound impact on effective learning (e.g. e-learning, e-content, e-inclusion), make knowledge available through free exchange of ideas, abstractions and instructional interventions (e.g. BlindSpot cues). Computers can improve instruction and learning if used wisely and timely. The tutor's role will change dramatically now and in the foreseeable future, traditional teaching will evaporate and will be replaced by coaching, nudging, facilitation and guidance. This paradigm shifts research from scientific reductionism to a mere holistic social constructivism. In BlindSpot we focus on beyond-state-of-the-art learning in design and engineering education to research and develop multi-modal tools that will enhance the creativity during design processing. BlindSpot endorses computer-supported collaborative learning in which the individual user has learner control and remains a valuable asset in the design learning environment. Processed data assimilated as an emerging knowledge base becomes available as shared data repository, architecting on top of our memory and talents.

Technology enhanced and software-based learning supported with digital mobility devices or other will transform accessibility, location and presence. BlindSpot will transform the educational realm into a hybrid learning environment, in which the school/university/institute is the physical place for face-to-face interaction with your peers or educators, and peer-to-peer interaction and communication with your trainer/instructor/facilitator is holistically mixed with the e-realm through tele-presence, online learning (e.g. individual, collaborative) and online environments (serious gaming, story-telling, role-playing). In BlindSpot, facilitators/tutors will become personally engaged in the private and public dialogue with learners throughout the whole process of design ideation and conceptualization. Universal accessibility (e.g. EU wide) for all learners (e.g. novice and expert) will eventually meet the challenge of equal access to education there will be still many BlindSpots to address in this field.

Constructivist Pedagogy

We have discussed changes in the traditional learning and education process, influenced by the acquisition of new skills or up-skill whereby the changing role of the teacher/professor of the current one-way towards a two-way communication. The teacher/professor and the student/learner will provide knowledge, share experiences and information to the learning process. Potential exists for taking distance from a teacher-centred approach (passive learning) towards a learner-centred approach (Rugarcia et al., 2000). A move away from the use of the lecture as a knowledge-transfer activity to a more active student-centred learning environment (Deslauriers et al., 2011) has been shown to enhance academic performance. It also provides an opportunity to create space within the syllabus. BlindSpot will make these changes possible through the use of integrated technology and multi-modalities in tool interaction. To paraphrase (Caiero et al. 2004, Setzinger, 2006) the characteristics of constructivist pedagogy are:

- i. **Active and controllable:** it involves the students, so they are who interact and explore themselves; gives them the opportunity to be aware of the output of their own learning process;

- ii. **Constructive and reflective:** it allows students to gain new knowledge and accommodate to previous ones, which leads to think about their own learning;
- iii. **Intentional:** it lets the student to propose goals and to monitor his achievements until the proposed goals;
- iv. **Authentic, challenging and contextualized:** it helps students to set their learning in real situations, which prepares them for future challenges;
- v. **Cooperative, collaborative and conversational interaction:** it encourages students to discuss different issues, clarify doubts and share ideas in order to solve problems.

Special attention in BlindSpot is directed towards examining how students use tools in comparison to their professors: it has been noted that in general students are using tools more intuitively than their tutors. Following the approach of Gagné (1976) and based on research findings on intuitive hybrid design tools for collaborative interaction (Wendrich, 2010) it is noted that metacognitive skills are those handling and manipulation skills that the human being acquires and develops throughout his lifetime to manage his/her own learning, attention, and reasoning process.

Figure 6. *The Design Ideation Process (source: Wendrich, 2010)*

This concept is closely related to the IEK framework of rawshaping technology based on metacognitive control in intuition, experience and knowledge (Wendrich, 2010). When joined together (Feuerstein, 2003) praxis (practice) and knowledge can be incorporated in the learning process that encourages critical non-linear and reflective thinking. This educational strategy to enhance creativity can be summarized and illustrated as shown in Figure 6.

The BlindSpot project will develop a multi-modal tool for individual and collaborative interaction, which in some literature is referred to as Collaborative Project Based Learning (CPBL). It tries to solve

problems or tries to come up with plausible solutions and to give answers to a complex question or design task by the collaborative work of a student group. Depending on the tool and system part of the solution lies in the choice-architecture, reviewing and decision-making process that can be accessed by the user interface through the system. According to Badia (2006) and Wendrich (2010) there are seven types of tools that give support:

- i. A pleasurable environment that helps the professor/facilitator. It gives the educator information regarding to several questions related to the design and development of the activity.
- ii. Educational interaction between professor and student. It gives useful educational help that are stored in a given virtual realm.
- iii. Educational interaction among students. It eases the work of students in two ways: it favors his individual work; stimulates the collaboration with the rest of the team members.
- iv. An environment that helps, assist and support the students. It helps the student to keep in touch with the activity, assignment or task to be executed.
- v. ICT and the activity. It gives the chance to provide resources, cues, interventions and contents;
- vi. ICT and the relationship between the professor/facilitator and the activity. The professor makes the contents and other required resources available in order to make the activity feasible.
- vii. ICT and mobile learning technologies. Where facilitator and students can interact and communicate through the web (e.g. Web 2.0) with remote access, distributed computing and exchange of knowledge.

Connectivity and accessibility leading to a dynamic learning environment are beyond state-of-the-art solutions to encourage active learning and acquire knowledge through simulated real and virtual experiences. BlindSpot will address these aspects of enhanced learning and foster creativity in processes by letting learners:

- i. Trigger their imagination, intuition and idiosyncrasy;
- ii. Explore, develop or present ideas;
- iii. Create in non-linear fashion and allow ambiguity;
- iv. Motivate, encourage and stimulate utter and evoking ideas;
- v. Build confidence through risk-taking and shame-free interaction;
- vi. Work collaboratively;
- vii. Improve skill-set and professional competence;
- viii. Contribute actively to the innovation and its dissemination;
- ix. Reflect and incubate on results;
- x. Make choices and decisions that seem fit to solve the problem definition.

In conclusion we can say that the BlindSpot project widens the perspective and makes purposeful connections with people and their ideas. Currently there are no cost-effective competitors or applications that have the same or similar approach to this chosen setting. There are a lot of research articles and suggested applications that tackle the idea of blind spots but stay either within the scientific research realm or are not further developed to a tangible. However, with the introduction of Smart Technology (phones, pads and tabs) in combination with Web 2.0 we see an increase in development of smart cost-effective user-friendly apps that assist/support the user in virtual guidance, information,

playing and, e-learning. Consequently users also become developers changing the role dynamically as part of the crowd in the cloud.

Essential to spreading technology and applications is that the stuff should work, easy-to-use, user-effective, and efficient in use. New tools inspire new theories and models of learning and education.

In BlindSpot design processing we envision mixed realities where the user makes a cluster of plans, working back and forth between drawings, sketches, plans and models. The user tries and applies serendipitous ideas on the physical and virtual models, sees other opportunities, reacts to it, works on different scales and manifests a new set of iterations. Simultaneously, this being an iterative process it will be supported and enhanced with smart algorithms and creative tool technology.

Reviewing, reflection and track-back on the iteration process has an important part of enhancing creativity and will trigger the fantasy and imagination in thinking-and-doing. Colwell (2005) indicates, that the nature of engineering is to never design exactly the same thing twice. Every new design pushes the envelope somewhere: performance, cost, reliability, features, and capacity. Inevitably, some aspects of the new design will be outside the existing experience base. That's the part of engineering you don't learn in school. So how do you handle the wilderness areas of your design, those places beyond your comfort zone and the safety of your tools and direct experience? I think the answer comes down to how well you handle complexity.

Developing Creativity

There are many differing views regarding the concept and effectiveness of teaching creativity, however there is agreement in the literature regarding the need to nurture creativity and improve creative potential (Chan et al., 2005; Badhran, 2007; McWilliam and Haukka, 2008). The concept of active learning with the emphasis being on a learner-centred approach is one which is highlighted by many as an approach which will prepare engineering students to be adaptable and prepared for their future careers, (Baillie and Walker, 1998; Blashki et al., 2007). Some of the main approaches to creativity in engineering education are highlighted below.

Group-Work/Team-Based Activities are presented by many as being an ideal vehicle for promoting and developing creativity (Page and Murthy, 1990; Silva et al., 2009; Wong and Siu, 2011) with design providing an opportunity for team-based problem solving activities, which are authentic (Gómez Puente et al., 2011). Others highlight the importance of developing graphical, communication and team-working skills in engineering education (Murray and Renton, 1988; Page and Murthy, 1990). The environment in which these activities take place is important, with a studio format seen as being appropriate (Page and Murthy, 1990; Blashki et al., 2007). Use of open-ended design problems are recommended to promote creative thinking (Mahboub et al., 2004).

There appears to be a fairly widespread consensus that **exposure to and encouragement in risk taking** is important in creative education in engineering (e.g. Garavan and O'Connide, 1994; Badhran, 2007; and Blashki et al., 2007). McWilliam and Haukka (2008) similarly highlight risk taking as essential in promoting a creative environment and they argue that risk is minimized in an educational setting which is not conducive to creative development.

Divergent thinking processes are linked with developing creativity, and yet Törnkqvist (1990) indicates that engineering education does not generally encourage divergent thinking. Webster et al. (2006), as cited by Wong et al. (2011), refer to fostering of creativity through the use of both **divergent and convergent thinking**, with these happening at key stages of the design process. Howard et al. (2010)

focus on tool use. They refer to 'generation tools' such as creative analysis tools, creative thinking tools and creative stimuli tools. Success is then gauged through the measurement of 'creative performance' of a group, primarily through a measure of the number, speed, usefulness and quality of ideas generated.

Measuring/Assessing Creativity

Because creativity is seen as central to the successful education of engineers, it is essential that reliable and valid measures of creativity are used to determine whether educational methods are successful. For example, Mahboub et al. (2004) use the Torrance Test for Creative Thinking to assess the effectiveness of a creative training module. They report an increase in 'originality' and 'fluency' for an engineering group taking the module, an increase in 'fluency' for other students, and they concluded overall that creative training increases creative potential. The Torrance Test was also used in a study by Chan et al. (2005), with pre- and post-tests used to evaluate creativity. Again the findings were positive with an improvement in creativity measured in terms of 'fluency', 'flexibility', 'originality' and 'elaboration'.

Charyton et al. (2008) developed a Creative Engineering Design Assessment (CEDA) tool which measures 'fluency', 'flexibility' and 'originality' and includes describing design through sketching, material selection and end-user identification. In the development of their tool Charyton et al. reviewed the use of the Owens Creativity Test (used to assess mechanical engineering design), the Purdue Creativity Test (divergent thinking test), the Creative Personality Scale (CPS), the Creative Temperament Scale (CT) and the Cognitive Risk Tolerance Scale (CRT). The authors conclude that both divergent and convergent thinking may be key to creative engineering design and that incorporating creativity into the curriculum is likely to promote inventiveness.

The measures discussed so far focus on measuring individual levels of creativity, yet it may be as important to measure creativity in teams. Redelinghuys and Bahill (2006) successfully used a framework called the REV (resources, effort, value) technique for creative assessment of students or designers working individually or in teams. The method assumes that a creative contribution can be detected, the value of design can be expressed as parameters of the product and that the value of the design can be expressed in terms of resources and effort. The assessment requires an assessed, an assessor and a reference designer.

Nurturing Creativity - A case study

It is vital to create an innovation and creative culture amongst both undergraduate and graduate engineering populations. Creating space for students to experiment and take risks within a safe controlled learning environment will enhance their creative potential. It has been suggested that companies not nurturing creativity are leaving innovation to chance, this same comment could be made of universities. Many companies are working to develop ways of identifying creative and innovative individuals amongst potential employees as part of their recruitment process.

A novel approach to engineering education has been introduced at UCD, in the form of two new modules: 1) 'Creativity in Design', which promotes creative design thinking in the first year of the engineering undergraduate experience and 2) 'Innovation Leadership', which prepares Masters level engineering students for leadership and project management roles. The 'Creativity in Design' module develops the creative problem solving abilities of our 275 first year engineering students,

as a core element of their curriculum. Development and communication of design ideas through the process of observation, visualization, visual representation, verbal communication and physical representation is central to this module. Students, working in groups, are encouraged to develop creative design solutions and to critically evaluate and present their solutions. The basis of the creative approach used is shown in Figure 1. Students are introduced to techniques and tools of problem solving and shown the relevance of these approaches to all engineering design work. The tools and processes are presented through formal lectures sessions, however active use of the tools through studio design teamwork projects is a key component through which the students develop their creative potential and their ability to communicate design ideas. The studio-based approach has been influenced by the methods used in the Stanford Design School for graduate students and that used by the innovation design consultants IDEO. A key concept within the process is combining business, technology and user-centred/customer perspective within design solutions. At the Taught Masters level our 'Innovation Leadership' module prepares students to manage projects, lead teams and use innovation techniques to develop creative solutions. The development of facilitation and leadership skills of this group is achieved through the link with the 'Creativity in Design' module. The Masters students facilitate the small-group experience for the first year students, through their project management of the studio experience. This provides a sustainable approach to the logistics of provision of a small-group experience for 275 first year students.

Figure 7. The Innovation Process used in developing problem solving skills

Conclusion

We must challenge our students to take control of their own learning, encourage them to understand how they learn and to actively pursue knowledge. Our engineering curriculum must provide the opportunity to develop the students' technical and scientific competencies whilst also developing their communication skills, critical thinking skills and creativity. We must develop their ability to find creative solutions to problems, challenging them and engaging them, developing their skills within the engineering context integrated across the curriculum. Curriculum design and development for engineering education has traditionally been strongly directed by the accreditation requirements of the relevant professional bodies rather than being driven by pedagogical research findings. The required accreditation programme outcomes generally focus on: understanding and knowledge of scientific principles, problem solving, design of components, systems and/or experiments, an understanding of ethical standards, team working and communication skills development (EI, 2007) and (ABET, 2009). The core element of Design across all disciplines of the engineering curriculum provides an opportunity for the development of creativity, critical thinking, and communication and management skills. Harnessing the opportunity to develop these skills through Design from an early

stage of the engineering curriculum will afford students the opportunity to develop into innovative engineers. Engineering education must provide the students with a knowledge and understanding of scientific principles and fundamentals. Engineers need to develop the ability to apply this knowledge to solve problems, innovate and invent, identifying available resources and constraints. Effectively tackling and solving problems also requires communication with design team members, with the community and with other stakeholders. The approach taken in this initiative allows the development of these skills and the building of confidence required to successfully and creatively solve problems. Engineering education must develop inspirational leaders, those who are going to find creative ways of solving problems, adding value to the economy.

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Appendix D

Feedback form Stakeholders ProRail Value Engineering Session

Custom VE Sessie - Deelnemers vragenlijst (in Dutch)

5-11-2010

Hoe waarschijnlijk is het dat u dit systeem aan iemand anders zou aanbevelen?

(Op een schaal van 0 - 10)?

1 2 3 4 5 6 7 8 9 10

Is dit systeem een toevoeging aan uw werkwijze?

Ja, want:

.....

.....

.....

.....

Nee, want:

.....

.....

.....

.....

.....

.....

Zou u dit systeem in uw beslissingstracject willen gebruiken?

Ja, want:

.....

.....

.....

Nee, want:
.....
.....

Welke suggesties heeft u ter verbetering van het systeem mb.t. de volgende aspecten?

Samenwerking:
.....
.....
.....
.....

Beslisondersteuning:
.....
.....
.....

Archivering:
.....
.....
.....

Heeft u overige suggesties ter verbetering van het systeem?
.....
.....
.....

Session Documents ProRail Value Engineering Session

Alkmaar Station

Alkmaar - Schematisch

Alkmaar Aanzichten

Alkmaar-Finance - Totaal = € 16,1m

Alkmaar Impressies

Traverse plus roltrappen

Getuend op SO datum MR101618 versie 0 2 d d 17-08-2010

Appendix E

Overview of all HDT's and Interfaces

Webdesign Charlot Terhaar sive Droste, webdevelopment Sefrijn Langen

Prototyping and simulation of RSFF embodiments (2009) (in background Daniël Poolen)

Final RSFF Embodiment and RSFF-GUI - User Inter-Actor Léon Spikker (2010)

RSFF equipped with Kinect I and GUI - User interaction by Gijsbert Dossantos (2010)

HDT-LFDS Embodiment, Interfaces and GUI (2010) - Prototyping by Olaf Grevenstuck, Daniël Poolen, Werner Helmich, Herman Weeda, Robert Wendrich

Various LFDS Embodiments and Setups (2010 - 2011)

LFDS Flitecase I (left), LFDS Flitecase II including full colour printer (right)

LFDS Flitecase - 2011

HDT TUI's - Red Button, Footswitch, Adapted Numpad (2009 - 2012)

Computational Tomography (CT) in HDTE Framework

LFDS iPad - Software development Ninh Bui & Robert Wendrich (2012)

LFDS iPad with Nordic walking stick attachment (2012)

RSFF HDT with ArtTrack 3-D Scanner (2012) (bottom left), HDT framework equipped with Kinect II (2015)

NXt-LFDS prototype development by Luuk Booij (2013)

3-D Voxel Modeler UIF (Marcel Goethals, 2013)

3-D Voxel Modeler GUI

RST 3-D Voxel Shaper (2013) and Library (bottom)

Collaborative Cloud Design Space I and HDT Framework(2014) and Web GUI (CCDS)

CCDS II and Web GUI (2014 - 2050) - Prototyping by Marcel Goethals and Robert Wendrich

NXt-LFDS final prototype (2014)

NXt-LFDS Embodiment, TUI's and GUI-Touch IF (2014) - Prototyping by Luuk Booij, Olaf Grevenstuk, Werner Helmich and Robert Wendrich

NXt-LFDS GUI by Werner Helmich (2014)

HDT-Cross-Sectional Design Synthesizer and Web GUI (CSDS) (2014)

WebLFDS and Web GUI (2014-2050) © Werner Helmich and Robert Wendrich

HDT-LFDS with Frown IF (2015) - Prototyping by Jan Kleine Deters

HDT-LFDS equipped with 3-D Voxel Scanner (2015) - Prototyping by Arno van Dijk

HDT Air-Flow-Inter-Face (AFIF) - Prototype Pieter Pelt and Robert Wendrich (2015)

Various embodiments of hybrid design tools: Tangible Pods

HDT-Tangible Pods and HDT Framework (TP) - Prototyping by Peter Schaefer (2016)

Loosely Fitted Image Synthesizer (LFIS) Web GUI and Instant Results

HDT-Nxt-LFDS equipped with Oculus Rift in SVRE (2016) - Prototyping by Olaf Grevenstuck and Robert Wendrich

HDTE-IdeationLab on location in Public Space Rotterdam and Amsterdam (2012 - 2013)

HDT Interaction, Ideation and Iteration Galore by Herman Weeda (top) and Werner Helmich (bottom) (2010 - 2016)

HDT's in various scientific demo setups (2010 - 2016)

Olaf Grevenstuk, Werner Helmich, Ruben Kruiper (top) in HDTE with Elementary School kids
Leendert Verduijn (bottom left) in action with LFDS

*HDT's in various scientific demo setups - IdeationLab [Frontwise - JAM - Rawshaping Technology]
@ Dutch Design Week (DDW), 4TU 'Mind-the-Step' (2015)*

IdeationLab @ Dutch Design Week (DDW), 4TU 'Mind-the-Step' (2015). Arno, Betina, Charlot, Herman, Jan, Luuk, Merel, Olaf, Peter, Richard, Robert, Ruben, Sefrijn, Simone, Werner, Wilco...

HDT's and interfaces embedded in HDTE: 'DesignDrome'

HDT's and interfaces embedded in HDTE: 'DesignDrome'. Concept by Leendert Verduijn

*Virtual Reality Laboratory - Faculty of Engineering Technology, University of Twente (2004 - 2016)
Design by Robert Wendrich, Martijn Tideman, Ralph Klerkx, Wouter Eggink © 2004*

Appendix F

Survey Monkey Forms Websurvey - Triple Helix Ideation

CDI Analogue

1. Did you have previous experience with traditional design tools?

☐ Yes

☐ No

2. What is your experience with traditional design tools?

☐ Novice

☐ Intermediate

☐ Expert

3. I thought traditional design tools are easy to use.

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

4. Whenever I make a mistake using traditional tools, I recover easily and quickly.

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

5. I believe I became productive quickly using traditional design tools.

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

6. Overall I am satisfied working in this way.

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

7. Performing design tasks is fluent and straightforward.

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

8. How well does this mode of working meet your expectations?

☐ 1=Poor

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ 8

☐ 9

☐ 10=Excellent

9. I thought my creative output was succesfull.

☐ No problem

☐ Minor problem

☐ Major problem

☐ Failure/Gave up

CDI Digital

***1. Did you have previous experience with digital design tools?**

☐ Yes

☐ No

***2. What is your experience level with computational design tools?**

☐ Novice

☐ Intermediate

☐ Expert

***3. I thought the digital tools were easy to use.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***4. Whenever I make a mistake using the software tool, I recover easily and quickly.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***5. The interface of software tools I used are pleasant.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***6. I believe I became productive quickly using the digital tools.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***7. Overall I am satisfied working with these digital tools.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***8. Exploring features of software tools by trial and error.**

☐ Difficult

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Easy

***9. Performing design tasks is straightforward.**

☐ Never

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Always

***10. How well does this digital mode of working meet your expectations?**

☐ 1=Poor

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ 8

☐ 9

☐ 10=Excellent

CDI Hybrid Design Tool

***1. Did you have previous experience with the design tool?**

☐ Yes

☐ No

***2. What is your experience level with computational tools?**

☐ Novice

☐ Intermediate

☐ Expert

***3. I thought the tool was easy to use.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***4. Whenever I make a mistake using the hybrid tool, I recover easily and quickly.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***5. The interface of this hybrid system is pleasant.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***6. I believe I became productive quickly using this hybrid system.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***7. Overall I am satisfied with this system.**

☐ Strongly disagree

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Strongly agree

***8. Exploring features of the hybrid system by trial and error**

☐ Difficult

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Easy

***9. Performing design tasks is straightforward.**

☐ Never

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ Always

***10. How well does this hybrid design tool system meet your expectations?**

☐ 1=Poor

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ 8

☐ 9

☐ 10=Excellent

Where is the...

Hybrid Design Tools for Conceptual Design and Design Engineering Processes... TOSCA Project by author.

2009 - 2016

'every child is born a genius'
buckminster fuller

The thesis which I am putting to you is that in spite of all the good-intentions of designers, developers and well-meant design efforts by industry in recent decades to invent, create, produce and make better 'digital things' in terms of products and services to increase functionality, usability, experience or enhance pleasure in use and user interaction, there seems to persist a lingering dissatisfaction, frustration and use-inability with people in general in relation to and unfamiliarity with their realm of 'digital things.'

Understanding of the interface between people and any 'things' in mediation of technology calls for a calm, empathic, human, enactive and holistic approach to product creation and desired level of smartness in all 'things.'

The 'jumping together' of knowledge by linking multi-disciplinary and cross-domain areas is beneficial for active sharing of knowledge. This will enrich variety, diversity and serendipity in the discovery of overarching methods and solutions from other disciplines and synthesize mixed contexts.

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