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Distributed Cognition, Mimic, Representation and Decision Making

Hybrid Interaction Environments in Support of Collaborative Design Processes

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Abstract— **On-going [re]search and experimentation has lead to further development of our Hybrid Design Tools to support individual or collaborative design and engineering interaction. The Loosely Fitted Design Synthesizer (LFDS) we present here is a synthetic design environment based on interaction with mixed-reality. The user-centered (human-in-the-loop) approach in conjunction with computational assistance affords intuition, creativity, stimulates interaction and triggers ambiguity in iterations. The user has real-time control through the use of a special interface and allows intuit decisions in choice-architecture. The real-time high definition video captures convey a time-line and iterative listing of these instances whereas the interface allows synthesizing the iterations. We demonstrate collaborative experimentations present users' performances on tangible ideation tasks and describe our initial efforts to integrate the results and findings into this hybrid design tool system.**

Keywords-component; hybrid design tool; collaborative interaction; intuition; simulation; mixed reality

I. Introduction

The hands are the instruments of the mind, to paraphrase McCullough [1], what would it be like to perceive our surroundings without the use of our limbs? Would we be able to understand the world around us fully if we only had, for example, to rely on visual and audio clues from our surroundings? Our perceptional playing field is far larger than vision and/or auditory alone. Our perception of an environment largely depends on the transduction of neural signals that are transmitted to several structures in the brain ultimately at least some of the signals will arrive at a receiving area in the cortex of the brain. Between transduction and arrival at the cortex, signals from each sense organ pass through a series of synapses at successfully higher levels of neural processing. The output result from the input signal differs in some way from the latter, through transformations during the processing stage. Successive transformations that occur as the sensory signal progresses through the hierarchy of processing serve to refine the information it contains. [2] Each sensory system responds to a particular range of stimuli. In our [re]search and experimentations we immersed novice and expert designers and engineers in several arbitrary and make-shift environments in which they had to perform either individual tasks or worked collaboratively. The experimental set-ups in these environments where designed to investigate and explore how the senses could be triggered and what kind of stimuli brought out what sort of interaction and processing. Furthermore, we brought our experimentation and [re]search to a real-world business environment. We use the system to analyze and evaluate collaborative interaction within a custom value engineering (CVE) scenario. We will present results, observations and findings of these sensorial space experiments which constitute the foundation of our system tool embedding and integration. To conclude we present the Loosely Fitted Design Synthesizer (LFDS) to show individual and collaborative design interaction with tangible materials and artifacts. The ambiguous iterations intuit instances in on-screen visualizations and become manifest representations of the loosely fitted design process progressions. Physical manipulation digitally assisted by a video capturing [3] system as an intrinsic part of the hybrid design tool augments and immerses the user in a mixed reality experience.

II. Physicality and Virtuality

A. Two-Hands, Two-Eyes, Two-Ears, One Nose, One Brain and a Mind of Its Own

Despite the increasing progress and availability of computational or digital representation and analysis, many designers and engineers still value the use of physical models in project planning, design process and engineering. The importance of adequate input/output user-interfaces, representation and conceptual modeling in synthetic environments is our research priority. In subjective and objective comparison between the analogue and digital design and engineering process the latter often default because of time-wasted on errors and problems, and compatibility of the users' and systems' conceptual models. We need to develop tools that stay close to our physical way of working and real-world perception. Tools that allow the same subtle physical freedom and gestural motions traditional tools and instruments embody. We need to create tools that support intuitive expressiveness, creative flow, rapid prototyping, allow speedy interaction and give sensory feedback. The challenge is to build interfaces and devices that synthesize these two-worlds and support the creative design process of compiling a representation with the computer as well.

B. Interfaces

Touch, feel, see, hear, smell are major part of our human senses that fulfill most of our needs and direct our interaction, behavior and decisions in the quotidian. With respect for all the effort and progress in virtual mimics of sensorial analogue features or aspects, current interfaces and devices are somewhat cumbersome and feel often unnatural non-intuitive. Three-dimensional virtual representation and interaction with i.e. haptic devices and multi-touch UI's are coming close to real-world experience but stay an approximation of the real. The feedback shows latency and the experience of immersion proves not always to be very robust. Our approach and hypothesis is to stay in the physical domain as long as possible, simultaneously assisted by a virtual synthesizer tool. Working this way it keeps the experience real through tangible modeling or representation and augments reality via digital representation. We keep the human-in-the-loop by placing the user standing in front of a workbench interacting analogue in sensorial space. Thinking-on-your-feet has a direct influence on knowing-in-action, cognitive response from sensorial input stimulates the mind, provokes thought processes and is instrumental to manipulative actions and gestures. Design ideation in reaction to distributed cognitive resonance triggers the senses and results in often chaotic ambiguous behavior simultaneously releasing creative flow. We encourage ambiguity in tangible design sketching or raw shaping. These iterative instances become manifestations of abstract conceptualization and represent progressions of ideas and creative solutions.

C. Hybridization in Virtual Environments

A hybrid design tool consisting of a real workspace on a horizontal or vertical surface enables distributed cognition and two-handed interaction with physical materials and objects. Real-time video captures convey a time-line and iterative listing of these instances, while simultaneously triggers speedy interaction, stimulates intuition and shows increase in level of detail. During the progression of ideation the virtual representation informs, directs and stimulates choice-architecture over time. This subsequently increases the spontaneity and serendipitous understanding of physicality. The affect being that mind-set is influenced by speedy tangible interaction thus increasing the number of iterative instances over time. After or during a progression it is possible to synthesize the virtual content by stacking, sorting, arranging iterations by i.e. decision or priority.

III. Experimentation and Interaction

The exploration and searching for new design tools through loosely defined projects brought us to further our quest towards humanizing design environments. We devised experimentations in abstract materializing and tangible representation in laboratory and real-life set-ups. We embedded creation of iterative instances without pre-conceived notions and allowing topsy-turvy design solutions or decision making derived from random materials in a variety of contexts. [4]

We introduce the following three (3) experimentations and show the set-ups for testing purposes:

A. Blindfolded Haptic Interaction

The blindfolded participants (sitting down) "Fig.7", are given either an audile instruction by whispering the task;"Re-create a model to size of an iconic car", in one of their ears or a tangible instruction to recreate an iconic artifact. The former is handed a wire size constraint and a set of wheels, "Fig. 1", the latter is handed a scale model of the iconic car, "Fig. 2". The assignment is to make a tangible representation using a formable mass. There is a five minutes time limit for both blindfolded tests. [2]

Figure 1. Set-up Tacit Experiment

Figure 2. Set-up Touch Experiment

The aim of the experiments is to measure, explore and quantify the effectiveness of tacit and tangible knowing using haptic perception to identify, recognize, re-create, mimic and make 3D-representation of shape without visual clues or stimulation. A formable mass affords interaction in manipulation and transformation during the process, "Fig. 3 and 4". Some of the results are shown

Figure 3. Tacit Haptic Experiment

Figure 4. Mimic Haptic Experiment

here, whereas the green objects are derived from tacit interaction, "Fig. 5", the red objects from mimic interaction, "Fig. 6".

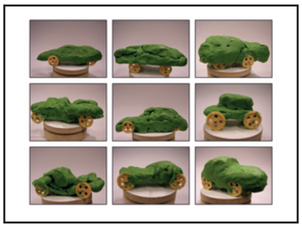

Figure 5. Tacit Haptic results

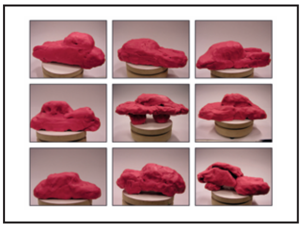

Figure 6. Mimic Haptic results

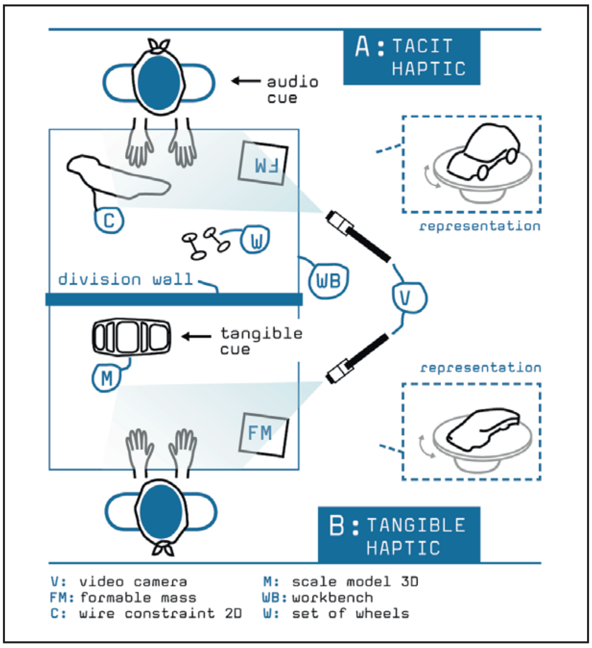

Figure 7. Typical set-up blindfold haptic interaction

B. *Cave Mimic Interaction*

In this haptic experimentation we immersed the participants in a cave, "Fig. 8". The set-up "Fig. 19" was to explore, observe and investigate the mimicking in interaction during a design process with tangible materials. We immersed two participants in the cave, both standing at their own workbench. The two workspaces are divided by a sliding-door "Fig. 9", the participants are not able to see one another. Furthermore, they are instructed not to communicate with each other. The task was to make haptic 3D-representations of an iconic car model. One participant is handed a scale-model of the car, the other participant is provided with a wire outline and a set of pictures of the car. The aim was to shape and transform ten (10) iterations during a ten (10) minutes period. Five (5) minutes period by oneself, after this period the sliding-door opens "Fig.10" and participants are standing face-to-face and are allowed to communicate and interact for another five (5) minutes and make iterative progressions.

Figure 8. Cave Structure

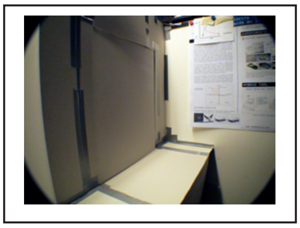

Figure 9. Sliding-door

Figure 10. Sliding-door Open

The aim of the experiment is to observe interaction and representation skills in various tangible materials constrained by time limit. Furthermore, we investigate how face-to-face [5] interaction and communication could enhance the process of mimic during iterative progression. In "Fig. 11" we show participants in the cave standing at the workbench during execution of the task.

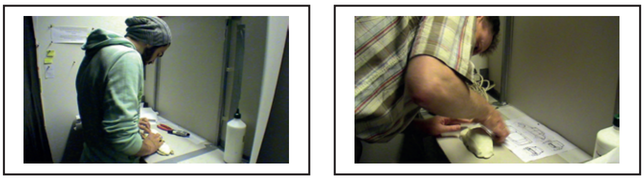

Figure 11. Participants in cave during solo interaction

In "Fig. 12" the sliding door is open and dual interaction is in progress. Sharing of information, materials and role-models is allowed.

Figure 12. Participants in cave during dual interaction

We were able to quantify the effectiveness and difference in approach when participants were introduced with either two-dimensional or three-dimensional role-models. The results were remarkably different and serendipitous. Participants working with 2D role-models were likely to execute rather two-dimensional than their counterparts. In our evaluation and analysis of the video recordings we discovered that speed during interactions has great influence on representation and enhances choice-architecture. In cave A (see also "Fig. 19") we noticed more 2D related modeling in the first five minutes mimicking the role-model outline (wire constraint) with the materials at hand. After opening the slide a more three-dimensional approach to the requested modeling was visible. In most cases the participant in cave B relied directly on the 3d scale model as a visual clue and stimulant. Some used the model as a tangible trigger for their iterations. In "Fig. 13 and 14" generic interaction and some iterations are shown of participants in cave A and B. Included are pictures of iterative results after full time, showing a mix (hybrid) in material usage, idiosyncratic constructions and a wide variety in form, size and shape. Materials available were a formable mass, form-rope, construction paper, white-glue and duct tape. We also supplied scissors and wire-cutters to facilitate the manipulation and processing during interaction.

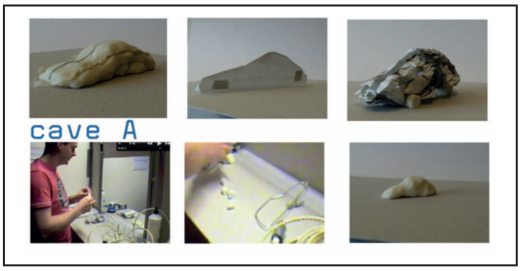

Figure 13. Cave interaction and various iterations

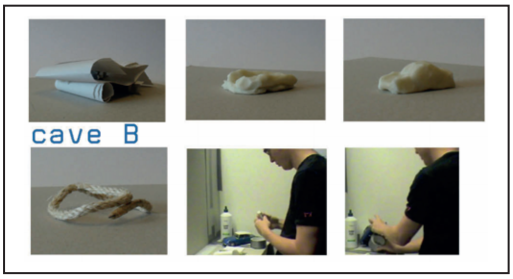

Figure 14. Cave interaction and various iterations

The level of detailing in the different iterations is also noteworthy in many cases the approximation of the symbolic form was more dominant then trying to match the role-models. Many participants focused their attention on the task ahead only and immersed directly in speedy interaction. They took notice of the supplied role models visually and merely used the information as a trigger. The interactions and intuitive representations mutually showed large differences in iterative results and material use.

Figure 15. a: clay model; b: paper model; c: form-rope & tape model

In “Fig. 15a to c”, the variety in shape and form are clearly visible, material constraints present themselves in the quality and level of detailing. Iterations shown are from cave A. In this particular case the participant executed and finished three iterations in 10 minutes of interaction. Noteworthy is the ambiguity in size and dimensioning, in this process the size constraint (2D outline) clearly was not used. “Fig. 15c” nudges visually closest to the role model as an abstract representation of the outer form.

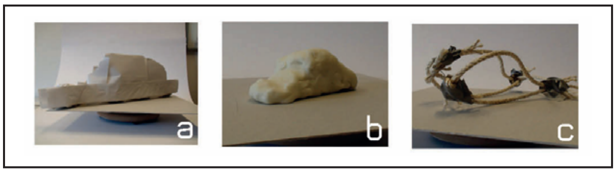

Figure 16. a: clay model; b: clay model; c: form-rope & tape model

Shown in “Fig. 16a to c”, are results from interaction in cave B. Little attention has been paid initially to the form and shape of the role model (3D scale model). Illustrated in,”Fig.16a and b” the proportions of the models are clearly not in tune with the scale-model. In this case the idiosyncrasy of the participant weighs more than modeling accurately. After opening the slide door this participant mimicked his counter-partner and used form-rope for an abstract representation, “Fig. 16c”. Interesting is the difference in quantity and quality of the various iterations, most participants created direct, intuitive and spontaneous. Often they created iterations without pause or reflect during the process. In comparison participants that followed the role-models were more precise in following the symbolic form and level of detail. Time constraints and pressure influenced most of the iterations in quality and appearance. This lead to idiosyncratic form objects that stem from their individual explicit and tacit knowledge. Meaning and form recognition, form mimic and loose interpretation directed the serendipitous results from sequential processing. The progression in time stimulated the creative process. Some results are shown hereunder and visualize a selection of iterations made during this experimentation by different participants, “Fig. 17 and 18”.

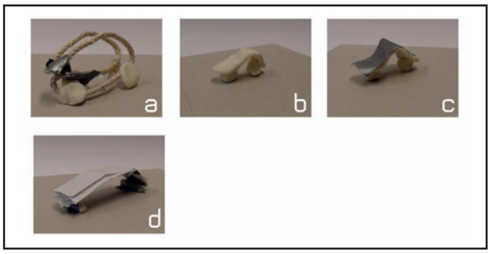

Figure 17. a to d: various iterations with mixed materials (hybrid)

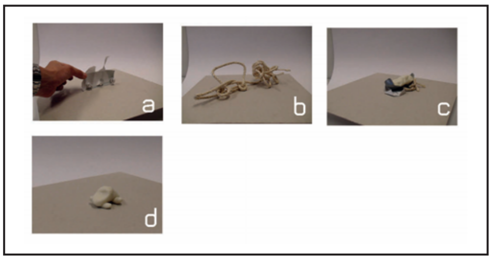

Figure 18. a to d: various iterations with mixed materials (hybrid)

Physical interaction and distribution of cognitive stimulus triggers decision moments over time and show increase in insight, spontaneity and understanding of physicality. It re-arranges the senses. Mind-set is affected and influenced by speedy tangible interaction thus increasing the number of iterative instances over time. Individual- compared to collaborative interaction showed that participants shared information quickly, handed over materials or role models when working face-to-face. In some cases the iterations made were shown to each other and mutually compared, direct mimic was observed only in some cases. However, change in material and modeling approach was observed directly after opening the sliding door. Most participants showed enjoyment and happiness when the door slid open.

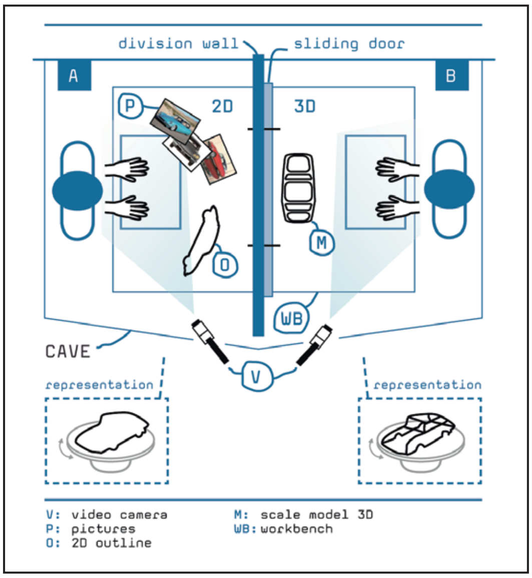

Figure 19. Typical set-up haptic interaction in cave

C. *Custom Value Engineering*

One of our most recent experimentations was to test the prototype of our Hybrid Design Tool (LFDS) within a real-world collaborative case-based scenario. This Custom Value Engineering (CVE) session was executed in close cooperation with ProRail BV in Utrecht, the Netherlands. ProRail BV is responsible for the complete railway infrastructure in the Netherlands and therefore has to work, communicate and collaborate with a variety of stakeholders to fulfill their targets and sustain their main mission to transport travelers from origins and to destinations. The testing and experimentation with the LFDS system was to support and assist the decision making and creative solution finding process between different stakeholders during this CVE project named ‘Station Alkmaar’ in the Netherlands, “Fig. 20”.

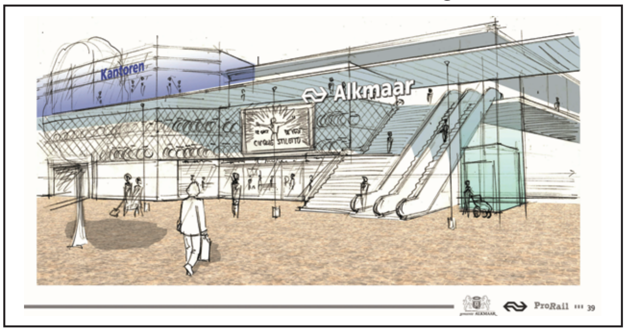

Figure 20. Artist impression Station Alkmaar

Twelve participants (stakeholders) were present, excluding the four persons RSFF [re]search team, during the session. The main objective was to immerse the stakeholders in real-time interaction and discuss real-life case topics engaged in a hybrid environment. Important aspect of this custom approach was to afford imagination, engineering and creative communication of various ideas, notions, trade-offs and constraints on the project. The LFDS worked as a focal point and assistant during the iterations of the various topics. Many instances were made from these interactions, the support system gave the participants control over choice-architecture and to make decisions between the various stakeholders seemed fluid and congruous. Group dynamics and mutual cooperation between stakeholders can be complicated and not often synergetic a lot of information and gathered data gets lost or is often not well structured or documented. To retrieve information of meetings afterwards, normally will be referred to in documents, minutes, notes, drawing’s either printed or electronic. Information that could contain; i.e. made decisions, generated results, formulated concepts, idea sketches, conclusions, important or relevant issues.

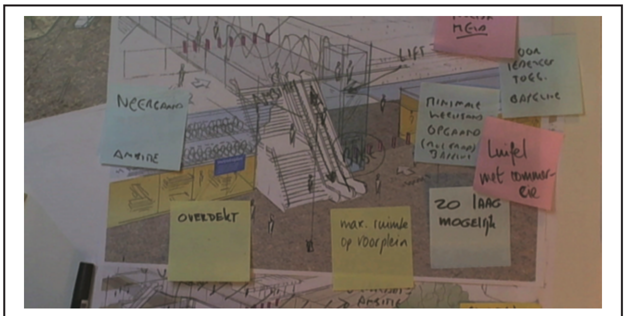

Figure 21. Iterations from collaborative interactions

In this case the LFDS was used to capture all the relevant data produced during the complete session. These instances are augmented and captured by a high-definition video camera and shown real-time on a monitor. The iterations are only stored (database) when the participant (-s) decide to physically push the red capture button. All the captured instances are real-time visualizations on display whereas the interface affords direct manipulation and synthesizing the iterations, “Fig.21”. After the CVE session all the participants were handed an USB-stick with the data of the case-study. We tested two different set-ups “Fig. 24”, during the CVE session; firstly we divided the participants (stakeholders) in two groups and made them interact with two separate LFDS systems. Secondly, we grouped them together and used one system to produce the collaborative iterations, “Fig. 22”. The tangible materials that were used during the sessions were post-it notes, drawing instruments, paper, tracing paper, renders, visualizations, artist impressions and contextual images of the current and future ‘Station Alkmaar’.

Figure 22. Collaborative interaction with LFDS

The explicit and tacit knowledge [6] was provided by the experts (stakeholders) standing around the Workbench sharing their ideas, interacted collaboratively and providing assessments on the case-based scenario. In our assessment and analysis of the interaction we discovered that to have a physical Workbench as focal point in a collaborative setting supported the liveliness, engagement and close cooperation. Grouped around the LFDS, actively participating in the on-going interaction or from time-to-time retreat to reflect upon the issues at hand enhanced the experience and collaboration levels. The evaluation with each individual stakeholder after the completed session showed us very positive response to the LFDS system. Verbal, narrative and visual information analogue and digital are spread openly, distributed and shared among the different participants (stakeholders) during the CVE session encouraged the collaboration and communication, “Fig. 23”.

Figure 23. Collaborative iterations with LFDS

The availability of all data and content digitally afterwards enables participants to trackback their process, interaction, choices, decisions in the iterative stacks and listing. Further values and benefits are in democratization collaboration, sharing knowledge, transparency in information structure to support dynamic work environments. With the LFDS it is possible to create a Virtual Office and immerse yourself in Cyber Collaborative Interaction (CCI). A drawback could be that face-to-face physical interaction is virtually limited in such circumstance.

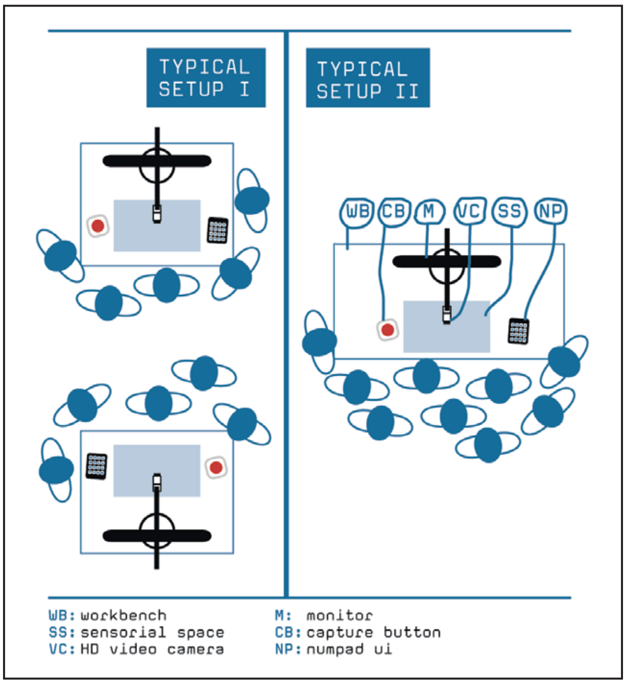

Figure 24. Typical set-up CVE with LFDS

IV. Analysis Method and Results Experiments

We used Video Interaction Analysis (VIA), [7] to investigate the gestures, expressions, collaboration, mimic, immediacy, iterations and interactions with the physical materials, hardware and software. Video recording enables us to make qualitative evaluations and observations. Data was extracted from the video footage from the various test environments.

We assessed a total of 196 participants during our tests varying from students, experts to professionals. We videotaped 20:37:00 hours of interaction during a five (5) months period, "Fig. 25and Fig. 26". All participants were made aware of the video recording but no further reference was made to the video camera during the assessments.

Experimentation Blindfolded Representation	A	B
	tacit haptic	tangible haptic
number of participants	79	79
total high speed video test time edited [mm:ss]	43:00	43:00
real total video test time [h:mm:ss]	7:13:00	7:04:00
average test time per participant [mm:ss]	05:29	05:22

Figure 25. Mapping + Results Chart VIA

Experimentation Cave Interaction + Represent.	10A	10B	10C
	tacit haptic	tangible haptic	tangible haptic
number of participants	20	9	9
total high speed video test time edited [mm:ss]	26:00	12:00	12:00
real total video test time [h:mm:ss]	3:20:00	1:30:00	1:30:00
average test time per participant [mm:ss]	10:00	10:00	10:00

Figure 26. Mapping + Results Chart VIA

V. Hybrid Design Tool

A. *Real and Virtual Realms Merged*

Merging and mixing reality is a challenge we feel has merit. The approach we take in bridging these voids is to link the physical analogue world to the digital virtual realm. We support two-handed physical manipulation of tangible materials assisted with virtual digital devices. 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. Manipulation and creative tinkering with various materials affords intuitive interaction and stimulates the mind. Being able to manipulate iterations in virtual space or reality enhances the creative notions, triggers imagination and widens the idiosyncratic scope. Our [re]search and development of hybrid design tools that can be used for i.e. creative sessions, design engineering or collaborative interaction are a symbiosis of the two-world challenge, "Fig. 27".

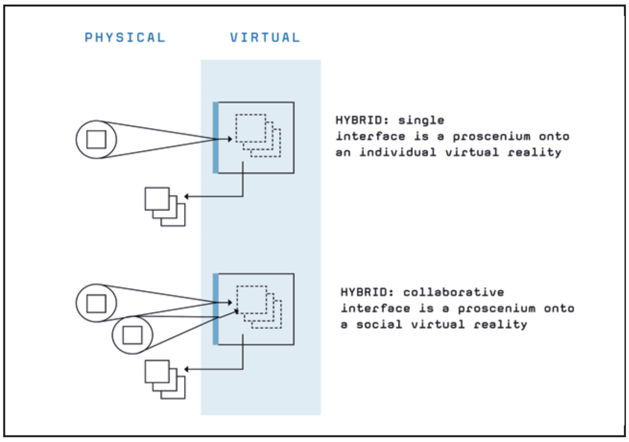

Figure 27. Two-world challenge: merging physical and virtual

B. *LFDS: Hybrid Design Tool*

The prototype of the Loosely Fitted Design Synthesizer [LFDS] "Fig.29" is a Workbench [8] with a horizontal or vertical workspace (sensorial space), monitor, HD video camera, standard PC and custom user interfaces, "Fig. 28". The two-handed user interaction takes place in the sensorial space with physical materials, objects or drawing instruments. Iterations are stored by capturing the instances of the interaction to push the red button. The user is in control of the interaction and decisive moment [4] creating loosely fitted iterations in the virtual. The iterative steps that are captured are visualized on the monitor screen and can be stacked, ordered, sorted, arranged, replaced, repositioned and so forth. The synthesis of the program allows the user full control over the iterations, choice-architecture, priorities and importance. The iterative listing is a real-time translation of all the transformations in virtual space. The

LFDS system follows and assists the user, the users intuit by learning-in-doing, knowing-in-action and thinking-on-their-feet.

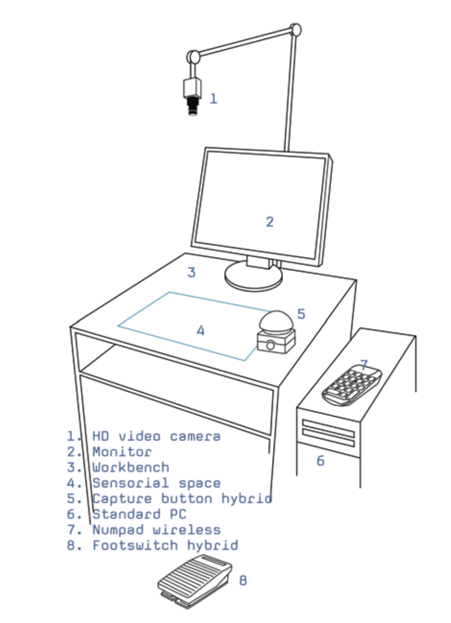

Figure 28. Set-up of LFDS: Hybrid Design Tool

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. [9] We place users in front of our system and ask them to complete a given task with the LFDS interface. 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, “Fig. 30 and 31”.

Figure 29. Prototype of LFDS

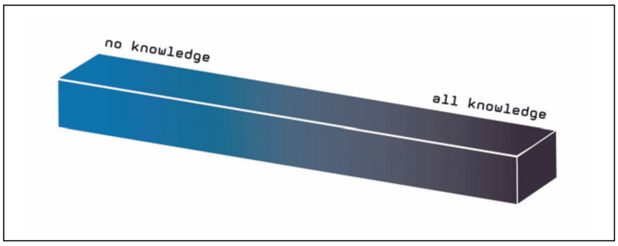

Figure 30. Knowledge space of interfaces [9]

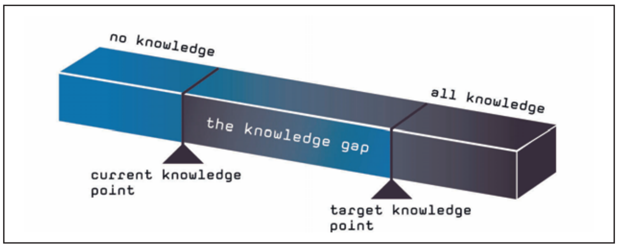

Figure 31. The Knowledge Gap [9]

The tangibility of the LFDS system affords the distribution of cognition and places the user in the centre of this Knowledge Gap. The user knows and is familiar with the physical world, design happens when users already know things. A comfort zone makes the user relaxed and focus on the task to complete. The hybrid interfaces of the LFDS triggers the users and increases their current knowledge, something will happen when you push the red capture button. The result is shown on the screen in front of the user real-time, “Fig. 32 and 33”.

Figure 32. Real time screen instance during interaction with LFDS

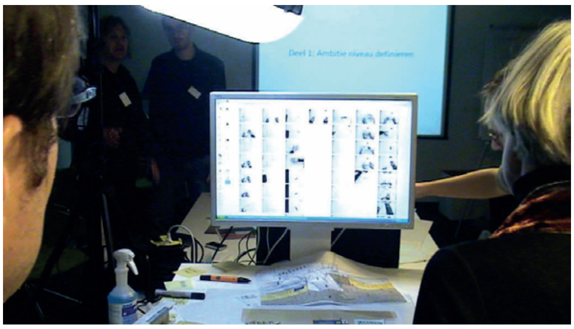

Figure 33. Screen with process instances of interaction with LFDS

By decreasing or reducing complexity the amount of knowledge needed by the user will change, the user interface will need less target knowledge. [9] Processing of the iterative information goes uninterrupted and is augmented by the high-definition video-camera captures. We are well aware that everything is an approximation, however up to now the results with the LFDS Hybrid Design Tool are promising and challenging. What we discovered during our experimentations and testing of interaction in variety of environments has lead to the development of this hybrid tool.

C. LFDS Infrastructure and Iteration Process

The infrastructure of the system is mostly based on components-off-the-shelf combined with custom-made parts. We use a standard Windows PC with XP \ 7 OS and input/output devices to support interaction. The software is programmed with Open Source platforms; for the interface, application, encoding and system layer we used Haxe [10], Neko and Screenweaver [11]. The Haxe code is compiled to Flash files for the graphical environment. The files are saved in xml format, the iteration movie is saved in MPEG format.

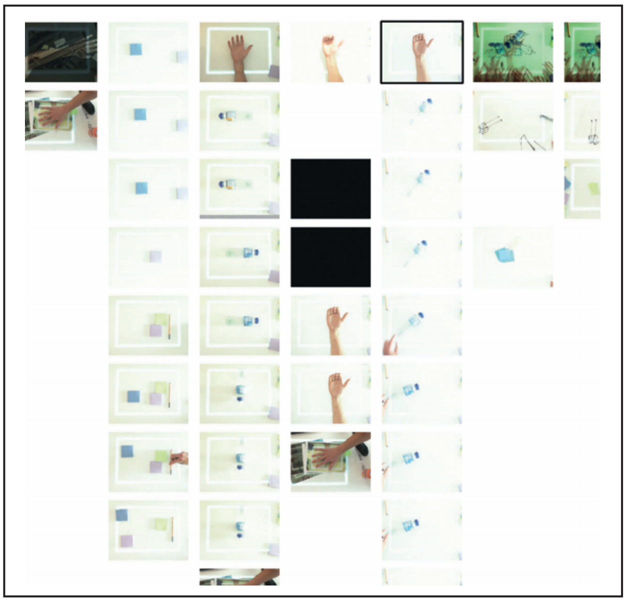

Figure 34. Iteration instances and stacks

The iterations are virtual instances "Fig. 34" and can be stacked (as shown in left top corner of figure 34) and manipulated virtually with the user-interface. All the captured data (iterations) are stored in a database. The iterative listing can be individually printed, stored, saved or exported as an iteration movie.

VI. CONCLUSION

Further [re]search, experimentation and testing is needed to gather more data on interaction, collaborative synthetic environments, intuition and user interfaces. The execution, results, video data and observations made of the conducted experiments show the complexity of the issues at hand. The hybrid tool we developed leads to further exploration and investigation of the analogue and digital realms. Placing the human-in-the-loop and focus the [re]search on the current and target knowledge point of the user. Making pleasurable and visually appealing interfaces and tools based on this notion, that even when the user is unaware that the tool is helping the interaction process, training is in progress. The user is being trained, but in a way it seems natural.

VII. FUTURE WORK

Currently we are working on a mobile version of the LFDS Hybrid Design Tool based on Pad Technology and video capturing. Furthermore, a next generation of the LFDS tool with multi-touch interface is being developed.

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REFERENCES

[1] M. McCullough. Abstracting Craft – The Practiced Digital Hand. The MIT Press, Cambridge, Massachusetts, 1998.
[2] G. Mather. Foundations of Sensation and Perception. Psychology Press, New York, 2009.
[3] R. Wendrich. Raw Shaping Form Finding: Tacit Tangible CAD. In Computer-Aided Design & Applications (ISSN 1686-4360), CAD in the Arts Special Issue, Volume 7, Number 4, 505-531, Spring 2010.
[4] J. Lehrer. How We Decide. Houghton Mifflin Harcourt Publishing Company, New York, 2009.
[5] M. Iacoboni. Mirroring People – The New Science of How We Connect With Others. Farrar, Straus and Giroux, New York, 2008.
[6] H. Collins. Tacit and Explicit Knowledge. The University of Chicago Press, Chicago,2010.
[7] B. Jordan and A.Henderson: Interaction analysis: Foundations and practice, The Journal of the Learning Sciences 4(1), 39-103, 1995.
[8] R. Sennett. The Craftsman. Penguin Books, London, 2009.
[9] J.M. Spool. "What Makes A Design Seem Intuitive?," UIE, North Andover, MA, 2005.
[10] http://haxe.org
[11] http://screenweaver.com