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MULTIMODAL INTERACTION, COLLABORATION, AND SYNTHESIS IN DESIGN AND ENGINEERING PROCESSING

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1. Introduction

We live in a fast and rapidly changing world in which computers play a very important, often dominant and crucial role. Especially in design and engineering education we notice how CAD technologies influence the teaching and learning spectrum. Novice students and/or first-time users willingly immerse themselves in the digital virtual realms and create virtual content galore. The exponential growth of the digital technologies and the affordability of COTS components make it within reach of many users to explore the boundaries in human-computer interaction. 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) Consequently this often leads to frustration, time consumption, problem reduction and mediocrity in finding the ‘right’ solution in problem solving. This is not to speculate that CAD has no added or intrinsic value or meaning, on the contrary CAD created a virtual world experience next to the real physical world in which we can create, simulate and visualize endlessly to some extent infinitely. Robertson et al.(2008) states that,”…3D CAD allows a designer to visualise and to “play” and with new ideas, that the increased efficiency of the design process allows the designer to spend less time on detail and more time on being creative , and that CAD promotes communication between colleagues, enabling richer ‘group creativity’.” In this paper we present empirical studies and prototypes of hybrid tools and multi-modal approach to stimulate and intuit interaction, ideation and creative processing based on distributed cognition, physical interaction and assisted by computational processing and synthesis. Furthermore, we will show that to process in a hybrid way the user experience will be enhanced, motivation stimulated and trigger enjoyment.

2. Design Experience and HCI

In experiencing the world around us we rely and depend on distributed cognition but also explicitly incorporate metacognitive skills, i.e. the use of our hands and feet allow us to better understand the physical realm and create spatial insight needed to explore your surroundings. Interaction with a computer and software is based mostly on using peripheral interfaces [input] and computational visual feedback [output].”Computers are a bit to rewarding...gives an instantaneous reward, requires something more the next second...instead of thinking, we are just pointing and clicking, and the result is "mouse potatoes"-people content to keep working a computer without pauses for reflection or quiescence” (McCullough,1998). “ Sener et al (2007) refers to this as, “...a legacy in which HCI for 3D CAD commenced from a conceptually opposite direction of text-based instructions (in Verplank, 2003).” There is hardly any natural, fluid or intuitive interaction possible to steer or direct the virtual visual information. ‘What good are computers, except perhaps for mundane documentation, if you cannot even touch your work?’ (McCullough, 1998). Sener et al.(2007) states that “...The general concern in the literature is that the creatively intense early phase of industrial design, where the form of a product is in a conceptual and ‘fluid’ state, is very poorly supported. Until improved digital tools are realised, industrial designers are resigned to adapt to 3D CAD essentially built for other professions (in Hanna and Barber, 2001; Sener et al., 2002).” We need to be able to express our thoughts, initial ideas, fuzzy notions or dreams to become manifest and convey to others in a spontaneous and intuitive way. “The more time people spend on learning and tinkering with computers, the less time they spend setting goals or applying existing skills” (McCullough, 1998). In design and engineering education i.e., drafting is almost universally computer-assisted line processing, however no tool will be as rich a conductor as the bare hands, it may compensate by working under a greater range of conditions. Sener et al. (2007) argue “...a recurring complaint from industrial designers is that 3D CAD is too rooted in engineering design, and is directed towards neither their own creative practices for defining the form of a product (i.e. the activity of ‘form creation’) nor their underlying need for sketching (in Hummels, 2000; Shillito et al., 2003).” However, haptic skills should play an equally important role in the fields of design and engineering, creating tangible artefacts, make use of tools and medium are just different ways of focusing our attention on the process of giving form, engineer and construct. To paraphrase Sener et al., ‘...accordingly, enactive computer interfaces have been identified as a potentially desirable, immediate and intuitive means of HCI for industrial designers (in Sener, 2007; Bordegoni and Cugini, 2006).

3. Creativity in Design Ideation: IEK model

Go with the flow is hard to do once rational thinking sets in. The methodological approach that encompasses design and engineering has lead to formally structured product creation process (PCP) which often gradually influence and constrain the creative spirit that is needed to reach over set boundaries. To transform an image in the mind’s eye or convey an abstract mental model there has to be equilibrium between explicit knowledge and tacit knowledge, both are based on knowledge, experience and intuition. The KEI-model is a standard educational approach for i.e. product creation processing with a preference for putting knowing and knowledge acquisition first. Next to this construct, we propose a reverse KEI-model: the IEK-model (Fig. 1) in support of our hypotheses that if all knowledge is explicit, i.e., capable of being clearly stated, then we cannot know a problem or look for its solution…therefore, that if problems nevertheless exists, and discoveries can be made by solving them, we can know things, and important things, that we cannot tell (Polanyi, 1983). According to Schön, 1983 our knowing is ordinarily tacit, implicit in our patterns of action and in our feel for stuff with which we are dealing. It seems right to say that our knowing is in our action and interaction. There are limits of technical rationality and knowledge, and can be identified as a gap between professional knowledge and the demands of the real-world practice. The gap lies in the fact that basic and applied sciences or education are often ‘convergent’ [silo], whereas practice is ‘divergent’ (Schön, 1983). In our model-diagram we include tacit knowledge, creativity and a mere intuitive approach to the cycle of design and engineering. The primary goal of design and engineering is to give shape, create or construct to an artifact – the product of design or engineering. The artifact is the result of a complex of activities – the design process. Design can be considered as “the process of creating tangible artifacts to meet intangible human needs” (Moran and Caroll, 1996).

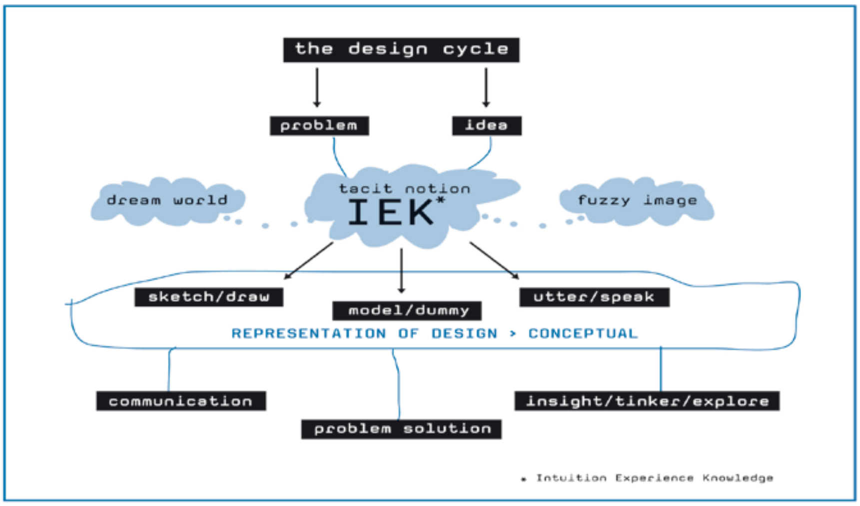

Figure 1. Intuition Experience Knowledge Model for a Design Cycle.

4. Qualitative Study on HCI and Design Representation

From January 2009 until early 2012 we have conducted more than a dozen experiments and studies on HCI, externalization and representation. The experiments ranged from very simple tangible representation to virtual haptic representation tests. A full account of all the methods, data collection, analysis, evaluation and results would be too lengthy for inclusion here, so we refer to its primary documentation (Wendrich et al., 2009; Wendrich, 2010).

5. Hybrid Interaction Tools and Multi-Modalities

"In short, we don't need fancy computers to harness cognitive surplus or enhance metacognitive stimuli; simple, cheap, flexible tools are enough" (Shirky, 2010). We authored and build prototypes of two hybrid design tools based on the research data from our studies and experimentations. Our approach is based on agile development, building and authoring. The hybrid tools incorporate multi-modal interaction with computational assistance. The first prototype RSFF [rawshaping form finding] (Fig. 2.) was introduced in Spring 2010 during Laval Virtual, France. The second tool the LFDS [loosely fitted design synthesizer] was introduced in Sept. 2010 (Wendrich, 2010) and will be discussed in this paper and results are shown of the latest case-studies and testing.

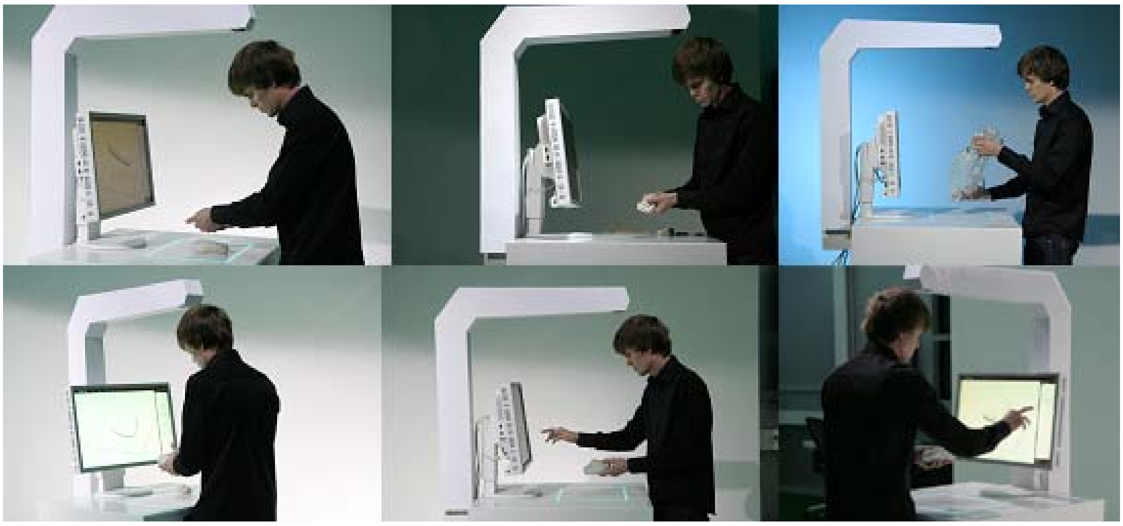

Figure 2. User interaction physical (top row) and virtual (below) with RSFF hybrid design tool.

6. System Overview and Architecture

In our experiments and setups we place the user-in-the-loop and the user (-s) have full control of the tool environment, idea-generation, creative decision-making and representation. The physical workbench includes physical interfaces, a computational- and vision system to support user-interaction. A monitor acts as proscenium to a virtual reality and conveys a visual representation on screen. Tangible and virtual interaction and representation through real-time engagement in a synthesized environment consequently leading to hyper-mediation being interrelated or to feel connected in mixed reality. (Fig. 3.and 4)

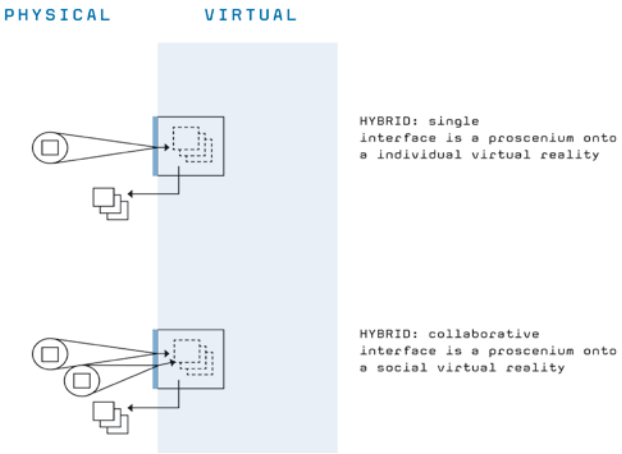

Figure 3. Physical and Virtual Representation with individual and collocated users.

The system generates at user-choice by pushing a capture-button virtual instances on screen that stimulate creativity in individual and/or collocated idea generation. The virtual instances [concept mapping] are real-time interpretations of user-interaction and stored as visual representations of the iterative interaction process. Stacks are blended iterations and show virtual instances merged (blue arrow in Fig. 6.), by use of the interface these can be un-stacked and viewed separately, selected or sorted (Fig.6.).

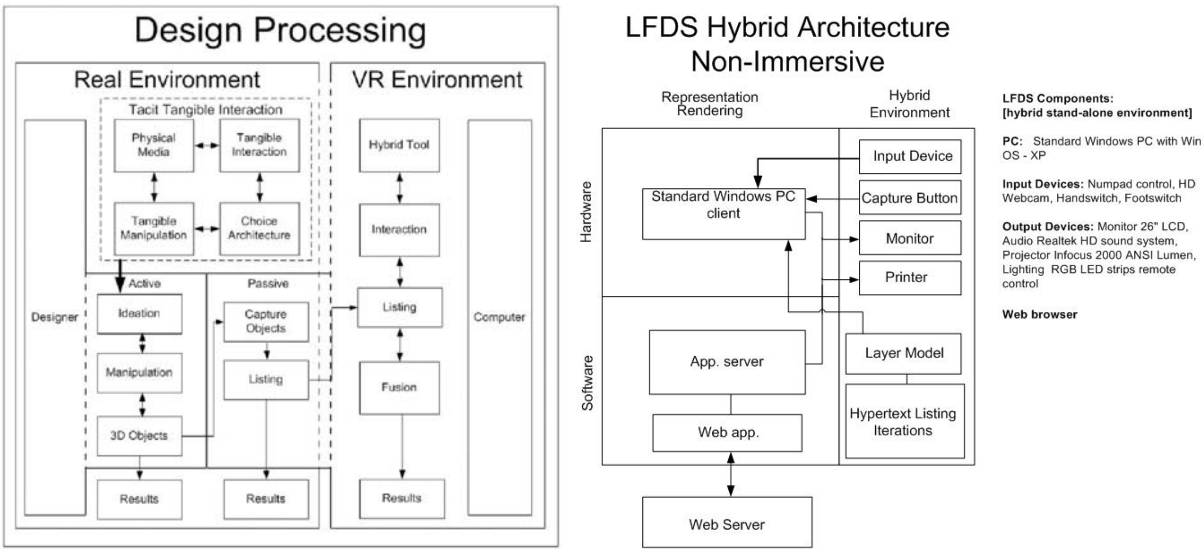

Figure 4. Design processing architecture hybrid tools and multi-modalities. (rsff ©2008)

Adapted wireless user-interfaces allow the individual user or players to stack, unstack, mirror, review, select, reflect, annotate and re-iterate the complete set of virtual instances or visual stacks. This fullloop approach, to synthesize the progressions through various modalities, encourage and stimulate the user (-s) to actively participate in the processing, reviewing, evaluation and representation of their ideas or concepts. In conclusion all data acquisition can be distributed, manifested, represented, re-looped and communicated either digitally or analogue by accessing the data repository. The LFDS (Loosely Fitted Design Synthesizer) prototype has different embodiments, as shown in Figure 5, to demonstrate the different flexible capacities of the concept framework.

Figure 5. LFDS workbench and flight-case setup.

The tool consists of the following components and parts; [...] a Workbench with a horizontal (sensorial physical space) or vertical workspace (virtual space), monitor, HD video camera, standard PC and custom user interfaces. The two-handed user interaction takes place in the sensorial space with physical materials, objects or drawing instruments [...] the infrastructure of the system is mostly based on COTS components (commercial-off-the-shelf) combined with custom-made parts. We use standard Windows PC with XP \ 7 OS and wireless 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, Neko and Screenweaver. The Haxe code is compiled to Flash files for the graphical environment. All the interaction instances are saved in .xml format in separate process files, the iteration movie is saved in MPEG format (Wendrich, 2010; Wendrich, 2011).

Figure 6. Typical virtual instances as representation of real-time interaction and concept mapping.

7. Case-Studies in Design Education

In this chapter we discuss two case-studies implemented in Industrial Design Education (IDE) at the University of Twente, the Netherlands. For our tests we used Bachelor and Master students to have them accomplish different assignments or design tasks in conjunction with the LFDS. All interaction sessions were videotaped with consent of the participants. Video data was extracted after each session and reviewed for analysis. All data was analysed and evaluated using VIA (Video Interaction Analysis) to observe interaction, manipulation, collaboration, gestures, multi-modality, latency, enjoyment and usability. In these experiments we assessed a total of 83 students and captured approximately 11,7 hrs of video footage.

7.1. Case-Study – Design Ideation I: Collaborative Automotive Artefact Design

7.1.1. Participants

We paired the 76 Bachelor students in groups, a total of 38 groups were formed. Age between 20 and 23 years old. They had no previous experience with the hybrid design tool. The group tasking was executed on two LFDS machines simultaneously and each group assignment lasted five (5) minutes.

7.1.2. Material and Method

The groups were only handed some simple 2D line-drawings of various “sets of wheels’ to trigger their imagination and fantasy. Traditional sketching tools, paper, post-it notes, and other common ‘office’ supply materials were also made available. Students had to follow the rawshaping method of two-handed intuitive manipulation of tangible materials to make a variety of iterations and representations of the assigned task in conjunction and assisted by the LFDS.

7.1.3. Mixed Reality Environment

Typical setup (Figure 7.) for the experiment and indicates the collaborative HCI configuration. During the session we allocated one facilitator per LFDS. All interaction and processing on both LFDS workbenches were captured on video for evaluation and analysis.

Figure 7. Typical setup experiment and collocated interaction - Design Ideation I.

7.1.4. Task, Performance and Results

The design task at hand was the collaborative representation of “an automotive device”, to shape, sketch, visualize and represent ideas and capture iterations based on individual and/or collaborative choice-actions in conjunction with the hybrid design tool. The collected data of all sessions were saved and stored in the system repository. The overall performance is indicated in the chart in Figure 8.

	LFDS 1	LFDS 2	Total
number of groups	19	19	38
number of iterations	591	490	1081
interaction time in hrs.	3.5	3.5	7.0
average iter./hr.			154

Figure 8. Performance chart interaction and iteration processing - Design Ideation I.

The acquired data (crowd source) of 38 sessions were made available through Blackboard Academic Suit server to all the session participants. Individually they had to execute a final idiosyncratic end result of the automotive artefact. All the final work was handed in as a design assignment (.pdf) through the Blackboard AS system. Specimen of typical results (virtual instances) of the idea generation process from collaborative interaction and the individually executed representations are presented in Figure 9 and 10.

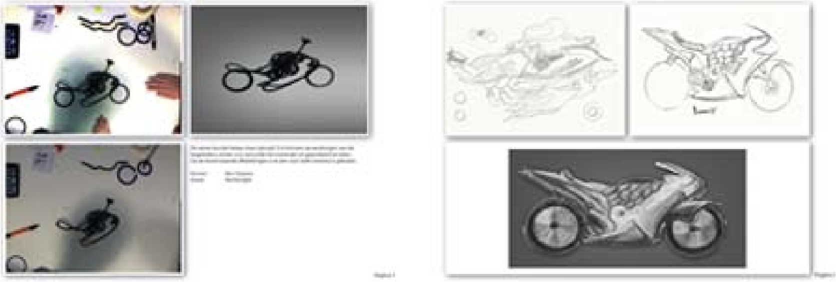

Figure 9. Specimen of Collaborative (left) and Individual (right) student work from LFDS interaction.

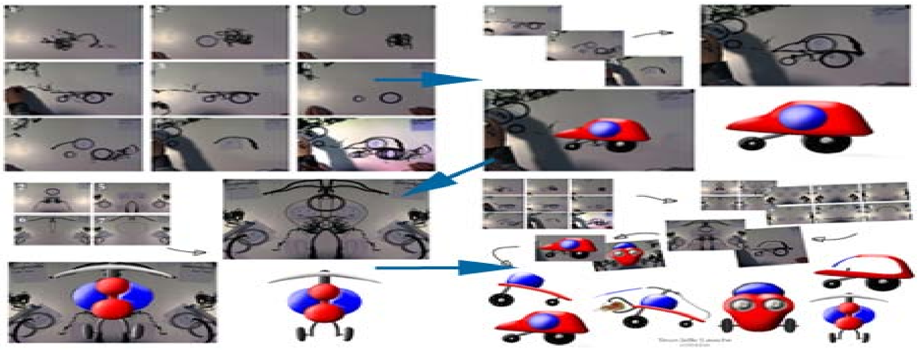

Figure 10. Specimen of Collaborative (left) and Individual (right) student work from LFDS interaction.

7.2.5. User Reflection

We did not ask any of the participants to reflect on the experiment, experience or individual and collaborative interaction, however in a large number of cases the participants gave some written feedback in the uploaded final documents.

7.2. Case-Study – Design Ideation II: Individual Product Creation Process (PCP)

7.2.1. Participants

We conducted the experiment on a total of 7 individual participants aged between 22 and 26 years old. Furthermore the participants were all 4th or 5th year Master students. They had no previous experience with the hybrid design tool. The experiment lasted thirty (30) minutes, however in most cases we allowed fifteen (15) minutes extra due to user-system stall, consult or other small delays. All the participants were approached personally and asked if they would like to take part in a design processing experiment.

7.2.2. Material and Method

The participants got a brief set of verbal instructions on the use of the LFDS and expected multi-modal activity. They were handed a DC-motor and power cord with plugs (Fig.11.) as core-functional tactile elements. A wide variety of other tangible materials, traditional design tools, artifacts and a hybrid tool were at their disposal. We observed and conducted an empirical study on multi-modal interaction and processing by offering a combination of a traditional desktop and LFDS workbench. The participants were asked to use both intermittently during tasking. The rawshaping method of intuitively bringing out ideas, fuzzy notions and mind images in conjunction with raw tangible and virtual shaping was applied in this use-case. During and after the sessions there was no further discussion allowed with the experimenters. This study is part of our on-going research in hybrid design tools in design and engineering, some of our preliminary results and findings are discussed.

7.2.3. Mixed Reality Environment

Typical setup and lay-out for the multi-modal interaction and PCP as shown in Figure 10 and 11(r.). All the interactions and sessions are captured on video for analysis and evaluation of the multi-modal interaction, synthesis and iterative product creation process. We did not yet analyze all interaction data, learning outcome or enhancement of creativity, the number of participants was too little to fundament a proper base. Our first 'rough' review of all the video footage from the seven case-studies indicated an interesting mix in use and approach of physical and virtual realities by the participants.

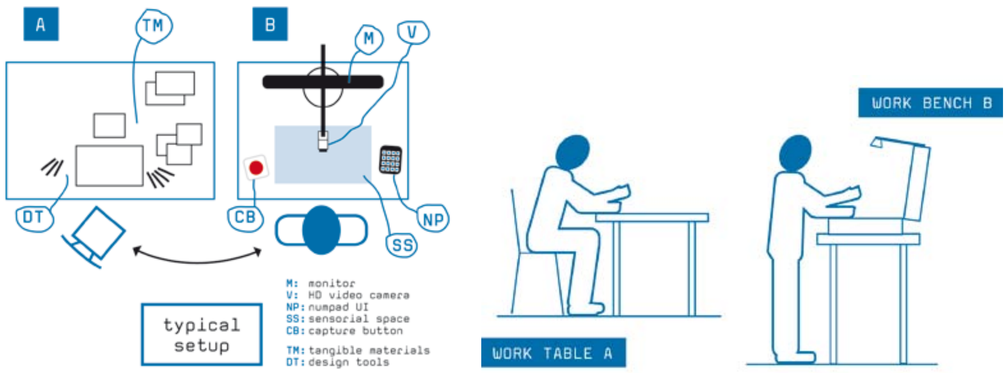

Figure 10. Typical setup experiment and multi-modal interaction - Design Ideation II.

7.2.4. Task, Performance and Results

The assignment was to create a product from 'scratch', to design and engineer an electric 'handheld mixer'. In two cases we introduced browsing an image-brochure for 5 minutes, with product photos depicting existing handheld mixers to trigger the imagination and fantasy. The performance in user interaction and number of iterations is indicated in the chart Figure 12. It shows a slight variance in iterations per minute for each participant. Overall performance of 62 iterations per hour for this individual experimental set-up and testing. HCI and raw tangible modeling, ideation and manipulation is shown in Figure 13.

Figure 11. DC-motor and power cord (left), mixed reality environment with tangibles, artefacts and LFDS (right).

								Total	
participant number:	1	2	3	4	5	6	7	7	
number of iterations	49	31	36	41	31	73	32	293	iterations
interaction time in min.	42	35	46	55	35	44	23	4,7	hrs.
average iter./min.	1.2	0.9	0.8	0.75	0.9	1.7	1.4		

Figure 12. Performance chart interaction and iteration processing - Design Ideation II.

Figure 13. HCI in mixed reality environment (l.) and raw tangible intermediate models (r.).

7.2.5. User Reflection

We asked each of the players to send an email with a brief reflection on the experiment, interaction, manipulation, transformation, and representation. They were asked to make an objective assessment of the multi-modal processing and indicate pro’s and con’s of working with the hybrid tool setup.

7.3. Analysis and Evaluation

In the reviewing of the video data we have three measures of performance: number of iterations, interaction time used, and average iterations per minute. In the first user-case we noticed that the use of a facilitator enhanced the interaction and increased the output between the group participants. This input was highly visible in the user-tool-interaction and iteration flow per minute. The facilitator supported the users by giving guidance and direction for e.g. nudging to make captures. First time users happen to immerse themselves in interaction and become intrigued by the tool system and modalities but tend to forget to push the red button in their excitement. The time constraints of five (5) minutes also lead to increase in speed and higher level of interaction. In creative collaboration and ideation the factor speed can be of help to stimulate intuition and progressions, working together assisted with a computational tool that gives instant feedback generates higher output. The total of 1081 iterations in 3.5 hours on two machines is the advantage of creative computational crowd processing (CCCP). To have a CCCP- repository filled with a multiplicity of ideas available to you empowers motivation, boost confidence and fosters creativity. It allows any individual (student or learner) to enhance their creative skills, idiosyncratic style and evoke imagination. In the written feedback we received from the students it showed that they highly appreciated working with the hybrid tool; *“Ik wil nog even kwijt dat dit echt een hele leuke opdracht was om te doen! BRAVO!!!”*, loosely translated it says; *‘I like you to know that this assignment was real fun to do! BRAVO!!!”* or ; *“Het was een leuke manier van brainstormen met deze computer werken. Veel is mogelijk hiermee, het is leerzaam en nog leuk om te doen ook!”*, which means; *‘It was a nice way of brainstorming with this computer. Much is possible with this, it is educational and fun to do too!’*(Google Translate).

In case of the individual PCP-design task we noticed a much ‘slower’ process of ideation and iteration this was partly due to the complexity of the task. However, rawshaping allows you an intuitive approach to bring out initial thoughts, fragments of ideas, make rough compositions in sketches or tangible materials and combine these with support of the hybrid tool to virtual models. The level of multi-modal interaction, transformation speed, tangible manipulation and design enjoyment was certainly visible during review of the seven session videos. However, if we look at the performance there is just some slight deviation visible in speed and number of iterations. There is only one outlier who made 73 iterations in 44 minutes (mean: 40 min.). Speed is not necessarily better in processing it all depends on the task at hand and leisurely dissemination of ideas and creativity. In the submitted reflections by the 7 participants the positive comments stated: modeling 2 and 3 dimensionally in virtual layers; real-time representation; modes of operation; transparency in core functionality and lay-out; scalability and enhancement of ideas. Some concerns were made related to the custom-made user interface (numpad) and usability. Furthermore, some indicated having trouble making the visual switch between the horizontal plane and monitor while processing.

8. Conclusion

We presented a multi-modality and hybrid reality approach for a collaborative and individual product creation process (PCP). In the collocated case study we focused on cooperatively externalizing and share creative crowd-sourced content to fulfil an individual design task. This approach facilitates the self-regulated learning, skill enhancement, knowledge sharing, and broadens individual experience. Consequently it evokes and intuits the creative processing in direct collaboration with others and by indirect use of shared content."...The fusing of means, motive, and opportunity creates our cognitive surplus out of the raw material of accumulated free time. The real change comes from our awareness that this surplus creates unprecedented opportunities, or rather that it creates an unprecedented opportunity for us to create those opportunities for each other...the low cost of experimentation and the huge base of potential users mean that someone with an idea that would require dozens (or thousands) of participants can now try it, at remarkably low cost, without needing to ask anyone for permission first..." (Shirky, 2010). In the second case-study we focused on integration of multi-modalities in conjunction with a technology enhanced hybrid environment for PCP. Reflection 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. The degree of personal participation, more than any degree of independence from machine technology, influences perceptions of craft in work..." (McCullough, 1998).

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