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A NOVEL APPROACH FOR COLLABORATIVE INTERACTION WITH MIXED REALITY IN VALUE ENGINEERING

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Mixed Reality, Value Engineering, Hybrid Design Tool, Collaborative Interaction, Decision Making

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 a hybrid tool as a Virtual Assistant (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. We observed the behavioral aspects during the various stages of user interaction, following the decision making process and the use of the tool during the course of the session. We captured the complete session on video for analysis and evaluation of the VE process within a hybrid design environment.

INTRODUCTION
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 1.

Figure 1 – 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, behavioral 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 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.

LFDS SET UP 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 horizontal surface (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 2 and 3.

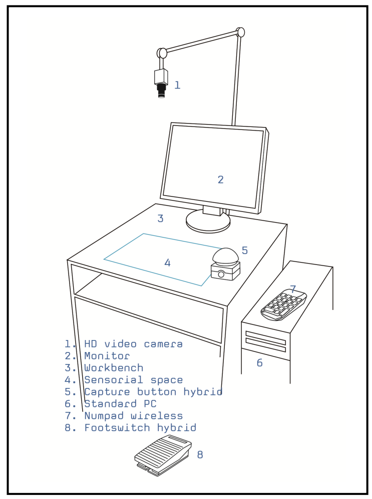
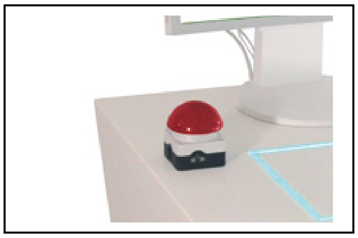


Figure 2 – SETUP LFDS

Figure 3 – 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 artifacts 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. [1]

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), see Figure 4 and 5 makes the capture.



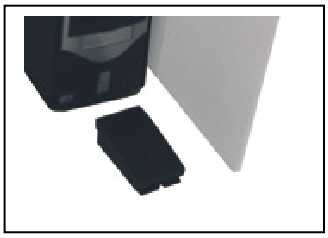


Figure 4 – CAPTURE BUTTON   **Figure 5 –CAPTURE PEDAL**

The full control lies with the actor and the system assists in the creative process. 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 is the benefit and contribution of this hybrid design tool. The instances and transformed instances are real-time visualizations on screen, see Figure 6. The layer-transparency, instant immediacy and active interaction in the physical and digital domain support the interaction, design flow and design processing. [1]

Figure 6 – VIRTUAL INSTANCES ON SCREEN

The iterations made within the interaction mode can be sorted, stacked, structured, selected and synthesized in the review mode as shown in Figure 7. With a special devised num-pad, see Figure 8, 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.

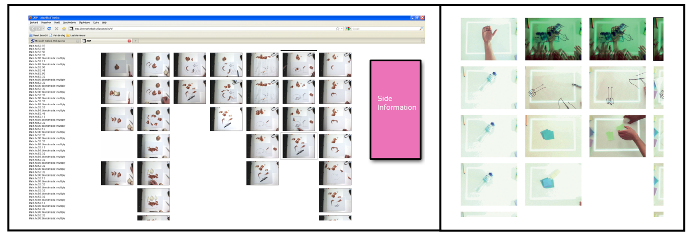


Figure 7 – TYPICAL REVIEW MODE SCREEN

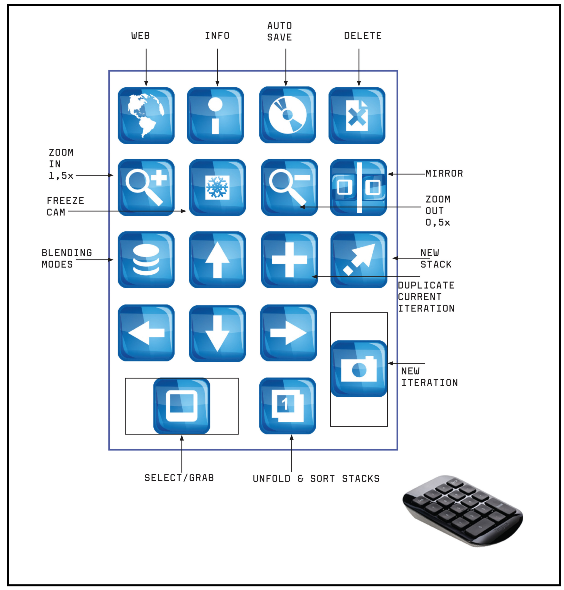


Figure 8 – NUMPAD WITH ICONS EXPLAINED

CUSTOM VALUE ENGINEERING WITH LFDS SET UP

Value Engineering 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 9.

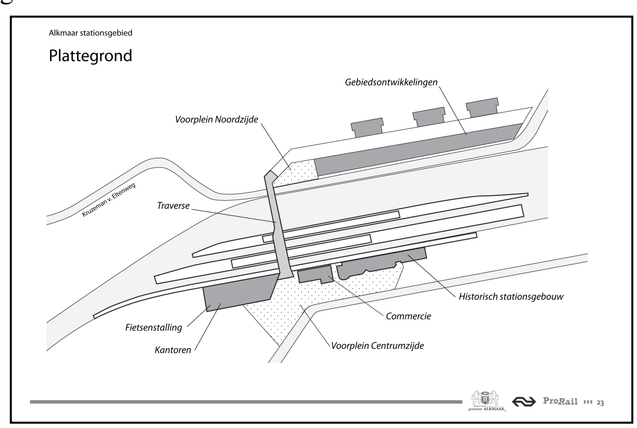


Figure 9 – SITE PLAN STATION ALKMAAR

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 10 and Figure 12, 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 Raw Shaping Society. After a brief introduction of the hybrid tool and the project scope the VE session commenced.

Figure 10 – TYPICAL SINGLE LFDS SETUP

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 [2] 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 make it 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. Direct visual system feedback affords to synthesize, 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 11 and Figure 13, with one hybrid system to semi-immerse 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 were 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 [3], 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 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. [3] 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. To paraphrase Billinghurst; '…collaborative AR interfaces can produce communication behaviors that are more similar to unmediated face-to-face collaboration that 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 introduction a discontinuity that causes collaborators to exhibit different communication behaviors. In a recent experiment we explored this by comparing communication behaviors 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…' [4]

According to Billinghurst implementing a workbench or table approach has merit to support seamless interaction.

Instead of using 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 mixed reality 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 value engineering 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 11 – EXTENDED WORKBENCH LFDS

HYBRID 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 [5] 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 intrinsic understand intentionality of action. [6] Thereby evoking and enhancing interaction, intention and behavior 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 press 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. [5] 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 behavior, 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; [7]

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.

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. [8] 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, 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. [9] 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.

EXPERIMENTAL SETUP

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 12 and Figure 13.

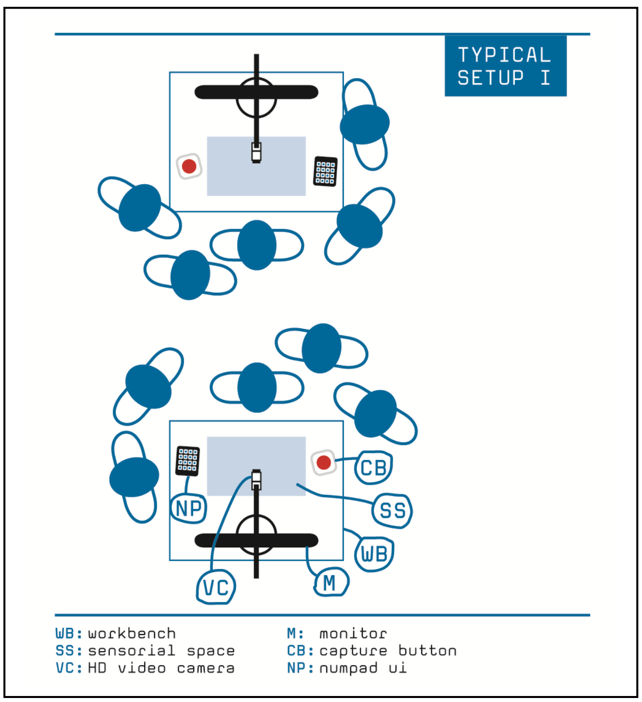


Figure 12 – TYPICAL SETUP EXPERIMENT CVE

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 [8] 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. [10] 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. [10] 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.

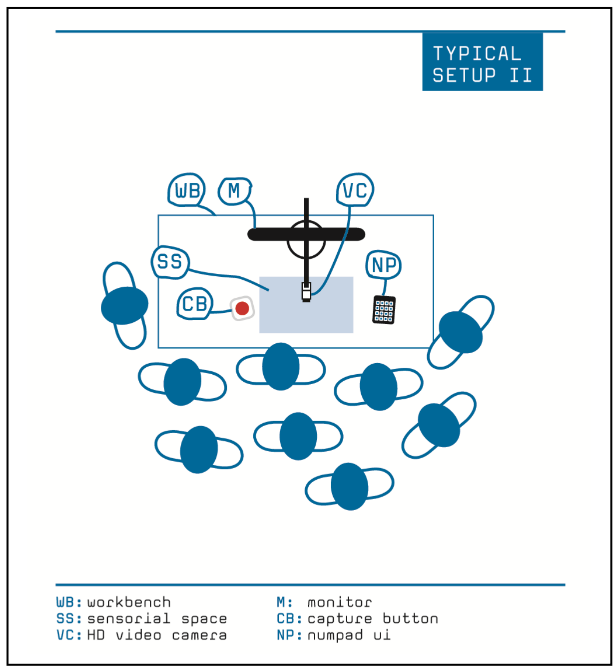


Figure 13 – TYPICAL EXTENDED SETUP LFDS

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 ambiance was ignited by this novel mode of working together.

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 14 and 15 clearly show this.

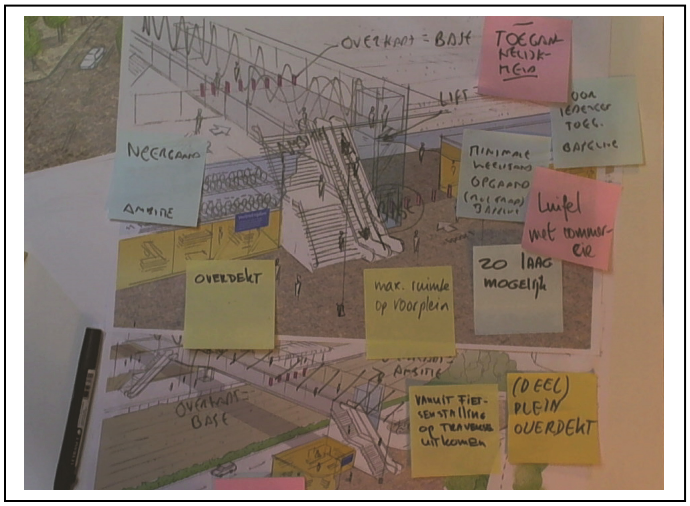


Figure 14 – ITERATIVE INSTANCES FROM LFDS

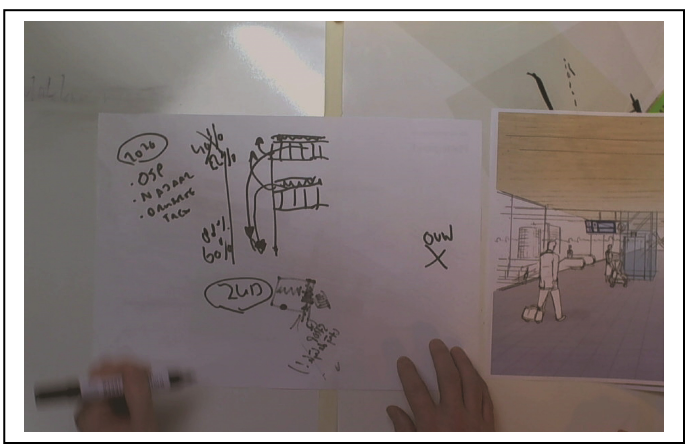


Figure 15 – ITERATIVE INTERACTION WITH LFDS

Possibly this was caused by newness to the system workings, unfamiliar with the interface, not used to log (capture) an iteration after action, no direct feedback of the facilitator or from the system. The control is with the user no cue is coming from the system or activated to warn the user to push the capture button. We rely on the human-in-the-loop to make up their mind and use tacit knowing to come to a decisive moment. [11] Besides, in a collaborative setting working and interacting with other players (stakeholders) could possibly lead to idiosyncratic or shared decisions. The goal is to come to a mutual understanding, accepting trade-offs, finding solutions that fit the specific requirements and lead to a successful interpretation of value-for-money results.

In the second half of the session with an extended LFDS setup we observed and experienced a complete different approach and results thereof show interesting ideational creations. Targets were more clearly defined, probably due to the contribution of extra visual and graphical content to the process. The facilitator positioned himself differently and only sporadically nudged the stakeholders into another target direction. The group of stakeholders appeared more together and showed more connectivity in interaction. We observed idiosyncratic individual behavior, 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 behavior. The results shown in Figure 16 and 17 represent a variety in solutions for specific parts of the envisioned project.

Figure 16 – COLLABORATIVE TANGIBLE INTERACTION

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

Figure 17 – INTERACTION AND REPRESENTATION

final execution and results. 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.

CONCLUSION

Value engineering 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 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 showed that a specific advantage of the hybrid tool is users being enabled to manifest everything that is generated. 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 said 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.

FUTURE WORK

Presently we are engaged in developing a second generation LFDS with a multi touch-graphic user interface, tracking and speech recognition capabilities. Another part of the [re]search is directed towards a mobile application of the tool.

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