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Harmonizing interoperability - Visions in embedding serious gaming in playful stochastic CAD environments

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Abstract

Computer-Aided Design (CAD) applications often promote memorable experiences for the wrong reasons. With numerous options coupled with poor user experience due to their complex functionality, the learning curve is often steep and overwhelming. There is little in way of invoking creativity as the CAD system is largely a platform to convey established geometry. Gameplay on the other hand tends to be regarded as memorable and formative experiences. Intuitive, imaginative, stimulating are attributes that spur natural creativity. If games are profoundly imbued for purposeful play, thriving on tacit and explicit knowledge of the user, a CAD system carefully stylized with ludic mechanisms could potentially be highly productive. This paper provides a framework for design synthesis on embedding serious game (SG) system models and applications in CAD systems. Various experiments were conducted to investigate user experiences, interface interactions, and engineer affect whilst carrying out design tasks in a game-based CAD UI. The emerging scenarios suggests the transformative approach transcend knowledge and understanding of relationships in CAD use and learning, play and interoperability associated with game mechanisms that enhance creativity and innovation.

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1. Introduction

The world of manufacturing is witnessing a dramatic increase in product variety as a result of the diversity of customer requirements, customer contexts, and the worldwide market harsh competition. The design process represents an important phase in the product development cycle, particularly due to the extensive negative impact of mediocre designs. Small errors are not discernible in the early design phases and they might not be apparent until the system is actually built or the product is produced. Consequently, co-design ideation spaces (CDI), in which the idea of a new product is developed and first designs are made, are aspects of innovation and creativity which play central roles [1,2]. Ideation is the “ability one has to conceive, or recognize through the act of insight, useful ideas” [3]. However, current CAD systems are governed by rigid rules and predetermined “canonical” procedures with limited attractiveness and interactivity thus limiting user/designer creativity.

Interestingly, gaming has extended beyond what was initially its natural boundary of entertainment and is now associated with the process of problem solving while providing analytical questioning of scientific viewpoints through active game-play (Table 1). The rules of game interaction or game mechanics include the concepts of usability and playability which are focused in a less complex environment which provides a more intuitive user experience (UX). In the process of CAD development and applications, the effective use and support of the users’ perception and their UX have been compromised by the engineering design system’s functionality and step-by-step evolution. The reason is that the problem-solution space is challenging, a complex balance between representation, generation, and search of a design space in pursuit of original design solutions.

Table 1. Summary of Current deficiencies and limitations of current CAD tools [4]

Complex menu items or commands.
Limited active and interactive assistance while designing in CAD.
Integration of informal conceptual design tools in CAD.
Inadequate human computer interface design; focused on functionality but not in usability.
Fixation on design routines that stifle users' creativity.

1.1. Revisiting current CAD structures

According to the experience of the CAD community, it is reported that users spend more time in learning the CAD system than actually using it. The most important challenges facing first-time users are: the ease of learning, ease of memorization and the use without errors. These skills are possible to acquire, in relatively shorter time by experiencing product design in a "Gamified CAD". The user experience and "interactional intention" are important for the design process, however, they are not easy to formalize in standard computerized systems. Games in general provide enhanced cues and/or notification of errors. In contrast VR-CADs are highly suited for immersive interaction with virtual artifacts, however notification of errors is judged by users themselves. The gamification of CAD provides the user with a stimulating design environment that is beneficial to the challenge of shortening the product development cycle and fosters oscillation across stakeholders.

1.2. The CAD-game conundrum

A game can be considered an abstract control system [5] where state-change during play and progress is controlled by rules [6]. In comparison, CAD (e.g. SolidWorks, Catia, ProE), provide users with input-tools for a variety of functions, where they proceed through stages and states of their work-project (Fig. 1a). The current CAD approach creates a gap between the user and the CAD system in such that the user experience, learning threshold, system functionality, performance and productivity are directly influenced and constraint (Fig. 1b). In CAD there are different event structures and different situations that the user has to deal with; however, the system still responds to the user's inputs based on its features. Engineers' perception and UX have been compromised by the system's functionality and step-by-step evolution (for example the function structures of Pahl & Beitz) [7]. Then, perhaps enriching CAD environments by applying gaming techniques and mechanisms may improve the efficacy of design and productivity while enhancing user experience (memorable and formative). In "Digital Natives, Digital Immigrants" [8], Marc Prensky cites a case where mechanical engineers learned CAD software by playing an FPS-like game called "The Monkey Wrench Conspiracy."

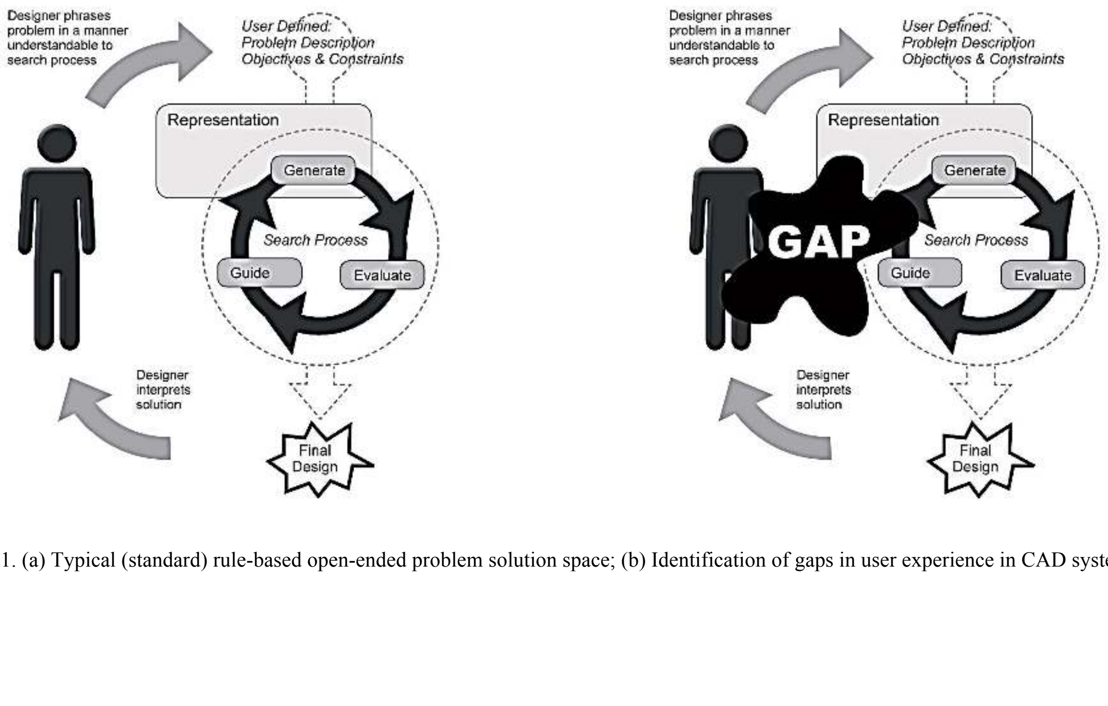

Fig. 1. (a) Typical (standard) rule-based open-ended problem solution space; (b) Identification of gaps in user experience in CAD systems.

Digital gaming systems are complex and comprise interactive technologies, media, and simulation technologies [9], often with a story/plot. Games could provide a context for creativity. Games host a variety of challenges ranging from decision-making and problem solving strategies through to action reflexes [10]. The online display of the user performance (e.g. scores) is a means for auto evaluation.

A game architecture can be approached using the tetrad of Schell [11]: aesthetics, mechanics, technology and storytelling. However, as Church [12] cites, “The design is the game; without it you would have a CD full of data but no experience.” Games and their design approach are different compared to traditional design and productivity domains such as CAD. Games actively encourage a variety of experiences while CAD strives for consistency at all times. Design is often viewed as a transformation from function to form, while the process of synthesis is the creation of a form that meets functional requirements. In CAD system design we could include both the game design and design synthesis methods to create a synthetic CAD eco-system architecture build around the prospective stakeholders. Within this eco-system the user intention is triggered, imagination is enhanced through enriched visualization and design/process flow.

2. User centered playground with stochastic CAD eco-system

The design solution space is always infinite and includes past, present, and future design states. This searching through the space becomes analogous to creating, designing, or inventing in design problems. If this space is describable to a computational game-based eco-system, then the challenge is to effectively find, search, and explore the solutions that best meet the demands of the design problem. A game-like environment has the potential to directly and positively reinforce the user experience and its creativity, as well as enhance new insights in understanding and learning. This design solution space enables the challenging task to target the problem definition in direct assimilation with the possible solutions that are emulated and represented by the CAD-Game System (CGS) (Fig. 2).

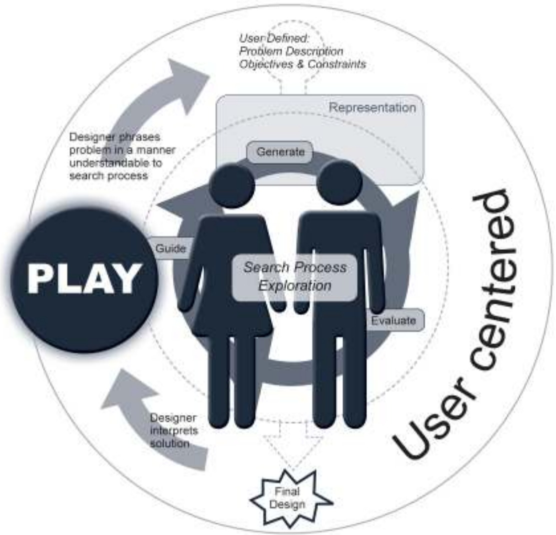

Fig. 2. User centered playground with stochastic CAD eco-system.

Furthermore, the CAD-Game System could introduce some randomness in finding neighboring solutions preventing to become trapped in a local neighborhood. The CGS nudges the CAD-players to keep on creatively tracking and backtracking to iterate and re-iterate in the design solution process to provide more than one final design outcome. Embarking on a quest to develop/implement serious games (SG) for CAD (complementary classroom/industry training, technology enhanced learning, even across domains from enterprise to manufacturing management), requires a checklist of design criteria and considerations. Success depends on the SG appropriateness to the objectives, the task(s), the stakeholders and the content. Given numerous solution providers, how can organizations make an intelligent decision on whom to trust with this mission critical system? From a provider’s perspective, how can developers sort out interoperability with legacy systems while providing the appropriate mechanics for learning? These are just some of the real and persistent problems associated with the development, implementation and acceptance of CGS. The general consensus is that bringing learning, CAD play and SG mechanisms/concepts together is fundamental to the future development of next generation CAD.

3. CAD-Game for enhanced creativity and motivational design

A game is an effective and engaging learning environment that is accessible anywhere, at any time, on demand, at your leisure and to your liking. Games can be a cost-effective solution (savings) to support just-in-time learning and education with periodic or continuous feedback. Consequently SGs could provide clues for improvement and adaptation in contextualized environments. Game playing offers learners motivation for acquiring new skills and/or to enhance the current skill-sets to improve individual capabilities [13].

Since communication is one of the most used and essential part of the design process, it fundaments the premise of using a game-infrastructure for CAD in support of users. Some games are very difficult to play, not least to master. The demands for the user(s) are based on a serendipitous combination of skills (i.e. IT skills, hand-eye coordination skills, tacit knowledge skills, cognitive skills, creative skills, technical skills, design skills etc.). The various levels of complexity and challenges are dominant features of game environments and are directly applicable to serious-fun CAD Game Eco-systems.

3.1. Intention, Experience and Inspiration

The creative act externalized during the early stage of the design process, wherein the ideational concepts are transformed and represented stemming from the mind's eye (inner visions), metacognitive aspects, imagination, mental divisions and distractions. Devotion and intent are fused together to bring out ideas and fuzzy notions to manifest brain generated content through the creative force and apply this in the creative act. The creative act initiates (ignites) with a complete and boundary less attitude towards inner and outer space, meaning that the current state-of-affair and context should have no bearing on the thought process or externalization of ideas. A CAD-game nudges (Fig. 3.a; Fig. 3.b.) the user to gain from solid forward motion challenge the design task at hand to bring to a possible conclusion with iterative solutions. To paraphrase Dalcher [14] we concur that design is neither orderly nor linear; it implies a continuous and active search to resolve trade-offs and satisfying constraints.

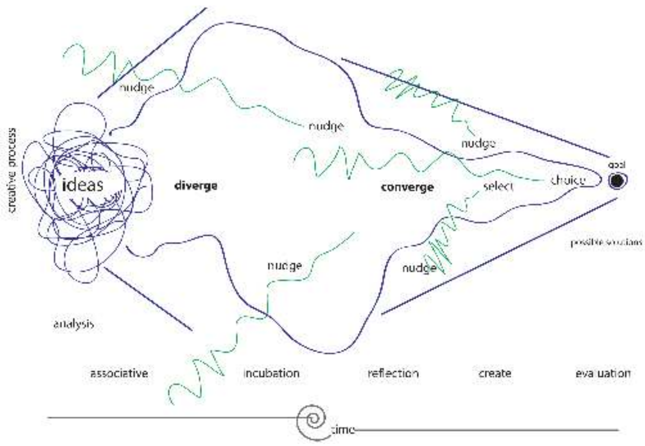

Fig. 3.a Gamification scenario for CAD [15].

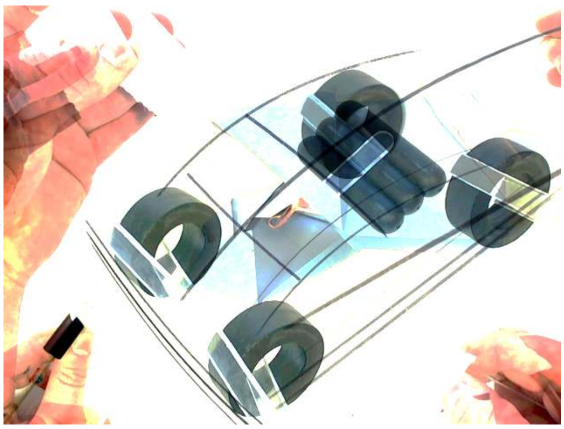

Fig. 3.b Possible collaborative interactive solutions.

Figure 4 shows how the creative human capability and capacity to playfully collaborate in design processing bringing imagination and inspiration to the design process at hand coincides with the intuitive natural human ability to interact, communicate, and challenge life force against creative force in a direct and/or indirect way [16, 17].

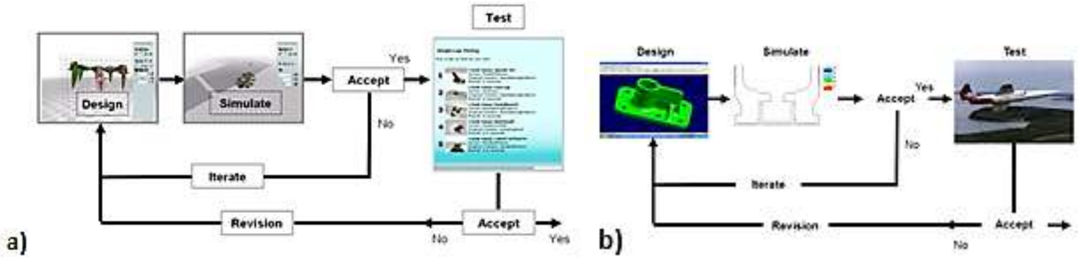

Fig. 4. Comparative game-CAD design and simulation scenarios. (a) CAD-game. (b) Conventional CAD.

3.2. CAD enriched by UX

When a CAD system is designed to accept input with the user defining the rules in comparison with the game system, is it possible for the game UX to be transferred to fit a CAD system? If so, gaming can make the user design process in CAD more interactive and meaningful. There are many studies providing a useful list of game-relevant issues and cognitive models that aid the understanding of the outcome of the experience [18, 19]. However none has been able to evaluate which game mechanics or set of game mechanics, cause engagement with a system. There is lack of statistical models to evaluate whether engaging and enjoyable interactions have taken place and under which specific game mechanics. For the purpose of the engineering design task experiments, the game mechanics intergrated to CAD are:

- *Goals*: Games state their goals clearly, therefore users will know what task is to be completed and they will stay in engaged with the system.
- *Performance Feedback & Status*: Games provide immediate feedback to users that can assess their progress and goals. User engagement levels can be increased in this way.
- *Progression Dynamic*: Games provide levels of progressive difficulty and challenge to sustain a user's state of flow.
- *Rewards & Achievements*: One of the most common approaches to motivate users is to provide points and rewards. Giving scores after the completion of a level can facilitate a user's progress assessment.
- *Graphical richness*: Games use a variety of graphics and aesthetics to be emotionally appealing.
- *Random and disruptive stimulants*: Sudden and unexpected events happen within a CAD-game scenario to trigger creativity in problem solution, imaginative way-finding in possible deviation outcome and forge spurts in agile adjustments and design directions.

4. Emerging Scenarios on Playful CAD Environments

Emergent progressions towards such environments have already been conducted to investigate how game mechanics can be implemented in CAD UI and how a new model with psychological relationships (engagement) mapped to the user interactivity with a system (user actions), can provide an insight in the metrics of specified game mechanisms progress in a system [20].

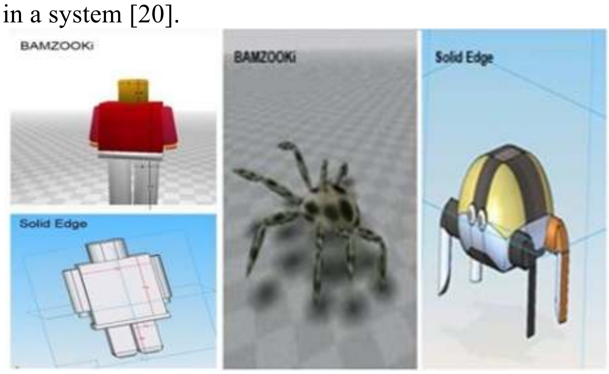

Fig.5. Design parameters: CAD-game vs. conventional CAD.

A preliminary study has been carried out which involved users divided in two groups - A & B - designing both in the game-like environment of BAMZOOKi and the commercial CAD package of Solid Edge V20 (Fig. 5). Group A designed a given task from a CAD perspective, focusing in the exact dimensions of the task. Group B designed a given task from a game perspective, focusing in the successful simulation of the task. The psycho-physiological measurements (EEG and GSR) of both groups were recorded, through physiological monitoring and feedback device.

The results showed there was a positive response of the users whose design interface was embedded with a game element. Especially the stress levels (GSR) and the creativity levels, which can be seen with an increase of theta waves (EEG), differed from the users who designed a task without the game element and who didn't show any significant changes in their emotional responses (Fig 6).

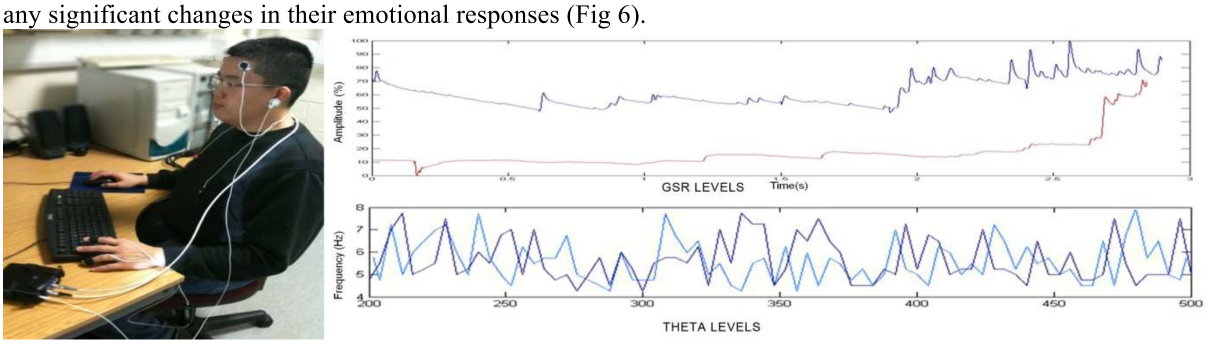

Fig. 6. Behavioural and neurophyisological response in CAD-game and conventional CAD.

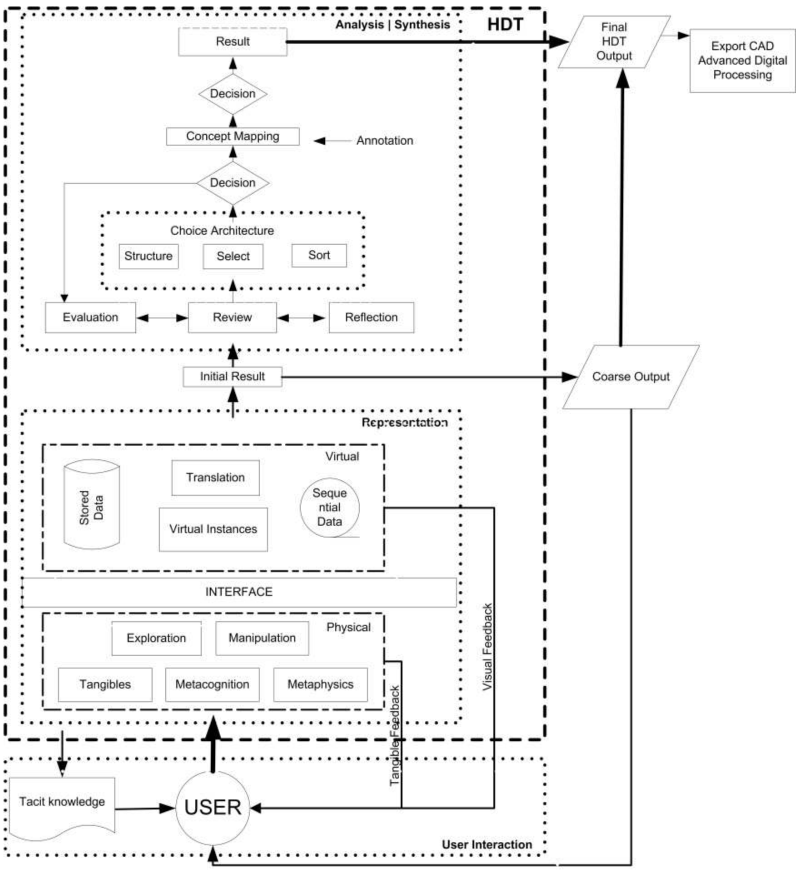

Fig. 7. Flow diagram of user-centered hybrid CAD environment embedded with fuzzy and logic mode.

The progression towards a boundary free Playful CAD environment in our approach to author and build hybrid design tools is to create mixed virtual environments (Fig. 7). Designers are being made into data processors, entangled and tethered in virtual digital realities with tools that are developed, directed and designed by system engineers and software programmers. It is apparent that loss of control, manual dexterity and intuitive interactions are surfacing while interacting or being immersed [21]. However, virtual reality environments are often so eluding and convincing that, to paraphrase Lanier [22], they become prone to changing themselves in order to make the computer appear to work better, instead of demanding that the computer be changed to become more useful.

5. Potential futures

To establish a trace about the usefulness of a CAD-game environment and the user experience when modeling a task in game-based CAD, industrial stakeholders were asked to optimise the design of an existing bracket to meet the functional requirements detailed in a design specification. As part of this activity participants used a parametric CAD design system [19]. Each session comprises two different user interface (UI) settings as shown in Figure 8. Each UI consists of two levels with increasing difficulty. There is no time restriction for the user to complete the task.

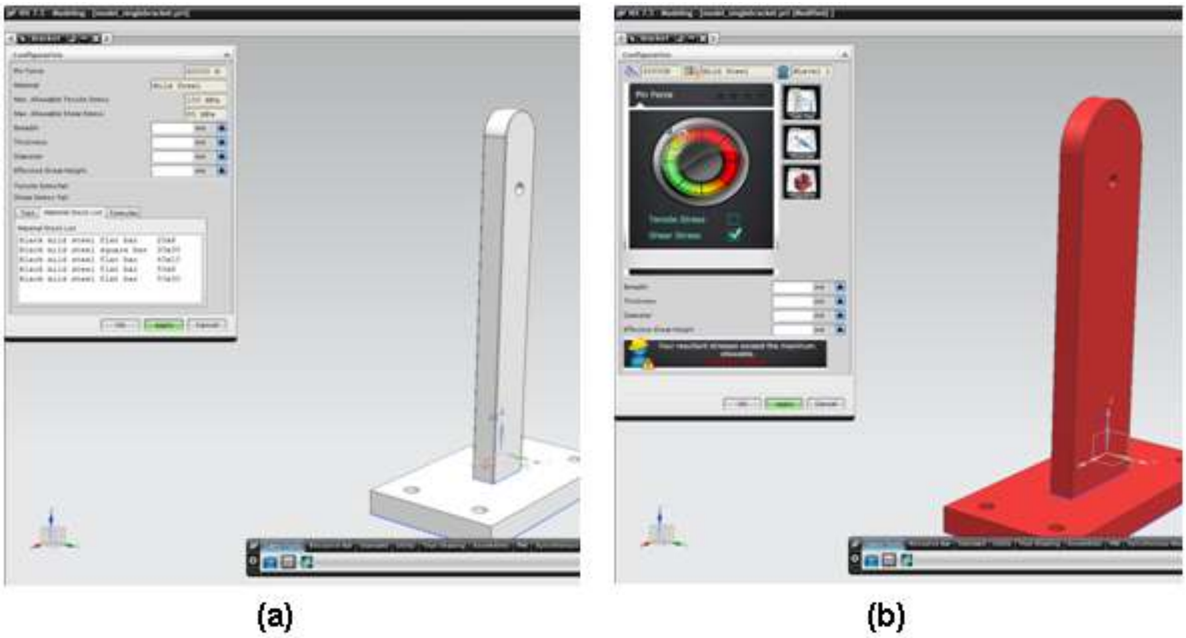

Fig. 8. User Interface of Bracket Design Experiment (a) Conventional UI/CADT (b) Game-like UI/CADG

From the affective response there is clear indication that a preference for a CAD-game architecture is more useful in design environments compared to conventional CAD (Fig.9).

Meta-cognitive aspects, creativity and intuitive user interaction were measured and observed in the creation of mental models of objects (representation), creation of design tasks (generation), analysis of how well the iterative outcome (solutions) meets the design goals and constraints (evaluation), and feedback on improvements to the design for the next iterative sequences (performance feedback & status) (Fig.10). By assessing their psycho-physiological signals and action log data, an interaction model was established identifying which of the proposed game mechanics contributed the most to enhance the user experience and to relay gain and winnings to the user's efforts (rewards & achievements).

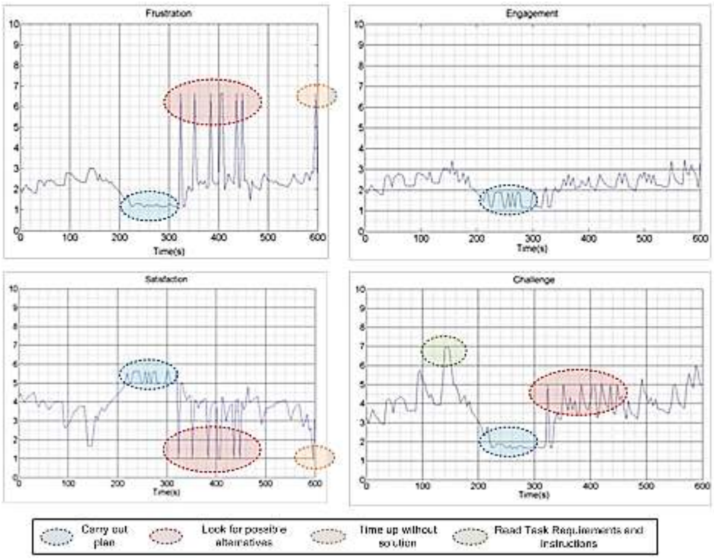

Fig. 9. Affect response of design task in CAD-game environment [19].

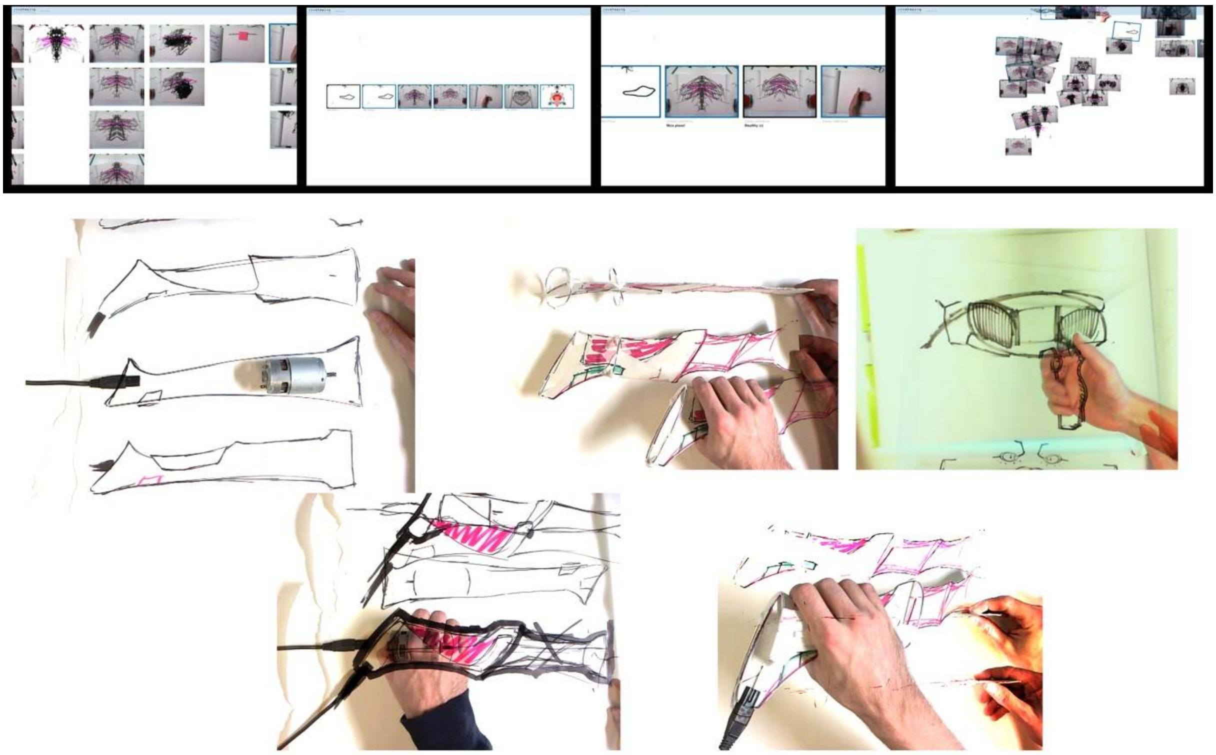

Fig. 10. Representation and generative content [21]

Assembly activity represents over 60% of the manufacturing costs therefore a system whereby engineers can build mental models for assembly planning in VE could be beneficial for the conceptualisation/ideation stage and the products' competitive route to market. In this respect it is important to meet the requirements of design for manufacturing and assembly (DFMA), Fig. 11.

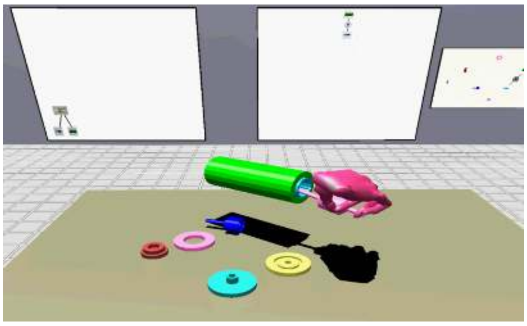

Fig. 11. Assemblability testing and generation of assembly plans in VE [23]

The integration of sensory feedback, such as haptics and audio, has already shown to enhance user performance [24]. However, there is limited reported research that includes SG in virtual assembly environment [25]. The generation of assembly sequence is a task that requires building mental models to develop strategies necessary to obtain not only feasible assembly sequence, but the most feasible sequence, generally called the optimum assembly sequence. The potential of including SG in assembly design and planning would provide important assistance to the operator in making decisions on which part should be assembled first in order to build the product. Operation sequencing via assembly trials for which the operator get notified about his performance with reference to the optimum assembly plan could enhance his skills by building mental models of assembly operations.

6. Conclusion

Due to the limitation CAD has on user involvement and creativity, a key question that emerges is how to motivate people involved in processes to participate in generating, evaluating and developing ideas. Such an environment can be created by employing game mechanisms as pointed out above. In our case it is important to integrate the game into the working process, i.e. the game has to be productive, contributing to an improved quality, shortening time-to-market and supporting the co-creative product development process. Knowledge developed during the game should be documented and presented to the participants in a way they can understand, , and in a format they can use for further work. The following considerations are proposed:

- Serious games have been applied to a diversity of domains from engineering to cognitive health to sports. Yet the role of game-based approaches as beneficial components to engineering design and manufacturing is often overlooked.
- Designed for strategic management, these games were not created for real product manufacture, hence the reticence of industries to use them.
- Cost effectiveness, strategic planning, and budget efficiency through interactive multidisciplinary design processing tasks including timely use of HR capital and capacity.
- Capturing and reusing knowledge unobtrusively without interrupting the design process yet augmenting the design activities and the decision-making processes.
- The rapid technological change requires sustainable adaptation of SG development through dynamic, yet synthetic mechanisms that avoid redundancy within SG research and development, regardless of the domains they are applied to.
- Awareness and level of acceptance of SGs within educational and industrial environments and at society level continues to be limited, and actions need to be taken to reveal the benefits of a SG oriented approach.
- Interoperability: cross-platform usage and data transfer can significantly reduce costs and time to market.
- The lack of credible metrics on the effectiveness and efficiency of SGs prevents the efficient implementation of SG, as it generates uncertainty at adopter level.
- SG methods can be applied to CAD providing a deeper understanding of design methods, processes and practice as well as a means of evaluating design quality, engineers' confidence levels and solution integrity.
- Early indication of how the engineer's psychological state may point to a means of automatically capturing decision cause,effect relationships, and key decision making rationale during design processing.

In the future, the authors will continue to investigate additional aspects of game design and game mechanics to facilitate CAD UIs and IUXs for serious playful creative engineering design tasks.

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