ANALYSIS, VALIDATION AND DESIGN: USING GAME ENGINES TO SUPPORT ERGONOMICS INTERVENTION AND DESIGN PROCESS

Esdras Paravizo
esdras@dep.ufscar.br

Daniel Braatz
Department of Production Engineering, Federal University of Sao Carlos
Rod. Washington Luiz, km 235, Sao Carlos - Brazil

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SUMMATIVE STATEMENT
Ergonomists currently use several tools and intermediary objects during the analysis, validation and design of work systems. The use of game engines (computer software commonly employed to design 3D games) can be a valuable tool to enhance the efficacy of ergonomics intervention.

Analyse, validation et conception : utilisation de moteurs de jeu afin d'appuyer les interventions ergonomiques et le processus de conception

MOTS-CLÉS
Moteurs de jeu, conception, simulation, objets intermédiaires

SOMMAIRE
Les ergonomes utilisent actuellement plusieurs outils et objets intermédiaires lors de l'analyse, de la validation et de la conception des systèmes de travail. L'utilisation de moteurs de jeux (des logiciels couramment utilisés pour concevoir des jeux 3D) peut s'avérer un outil précieux pour améliorer l'efficacité de l'intervention ergonomique.

PROBLEM STATEMENT
The engineering design process is regarded as a social process (Bucciarelli, 1988) in which participants from different areas of expertise, inhabiting their own “object-worlds” characterized by particular systems of symbols, constraints and instruments. It becomes fundamental for the success of the design process to effectively communicate across this boundaries as they are an ever-present obstacle due to organizations' characteristics of knowledge specialization (Carlile, 2002). In this context, challenges arise in the ergonomics integration into engineering design (Hall-Andersen & Broberg, 2014).

The ergonomic work analysis methodology proposed by (Wisner, 1995) and expanded by (Guérin, Laville, Daniellou, Duraffourg, & Kerguelen, 2001) has a clear design-driven final outcome: the improvement and transformation of work analyzed. The concept of validation during the ergonomics intervention is crucial to restituting information back to those who gave it and also allowing for corrections and complementation of the ergonomists' work (Guérin et al., 2001; Wisner, 2004). According to (Guérin et al., 2001), three moments are necessary for validation, the first when giving a feedback to workers the analysis performed, the second during the evaluation of the current situation diagnosis and solutions propositions and thirdly, in the evaluation of the ergonomics intervention as a whole, after the implementation of the proposed improvements. To achieve it effectively, the engineering design process associated must integrate the ergonomics knowledge generated on the situation.
The role of knowledge objects, artefacts produced and circulated by team members, is crucial to the development of the design process itself. According to (Vinck, Jeantet, & Laureillard, 1996) intermediary objects can be considered “closed” (when the user is bound to a specific use or interpretation of the object, designed by the person who produced it) or “open” (when the object allows room for interpretation and maneuverability). When utilizing an artefact as means to represent, learn about, transform knowledge and resolving conflicts across functions, the artefact takes on the form of a boundary object (Carlile, 2002).

Knowledge objects shape relations behaviors and attitudes as well as fostering coordination, cooperation and understanding among team members (Carlile, 2002; Vinck et al., 1996). These objects can take several forms, from physical scale models, full scale mock-ups, prototypes, sketches and blueprints to computer simulations, 3D renderings and so on (Braatz, Lopes, Camarotto, & Menegon, 2011; Broberg, Andersen, & Seim, 2011; Conceição, Silva, Broberg, & Duarte, 2012; Hall-Andersen & Broberg, 2014).

The advances in hardware and software development of the last decades render computational technologies more accessible to ergonomics practitioners and researchers alike. It’s not a surprise that current Ergonomics and Human Factors (E/HF) research and practice increasingly relies in computational supports for modelling, analysis, visualization and simulation of the various aspects of work systems, with special focus on physical analysis using Digital Human Modelling (DHM) and postures, movements and biomechanical analysis (Chaffin, 1997; Feyen, Liu, Chaffin, Jimmerson, & Joseph, 2000; Santos et al., 2013; Wilson, 1999).

These digital resources when appropriated by ergonomists and integrated into the design process may act as knowledge objects. Researchers have long used DHM software as a tool in workplace design activities (Feyen et al., 2000; Paul & Wischniewski, 2012; Santos et al., 2013). Recent researches however, point to novel technologies such as virtual environments and virtual reality as possible tools for E/HF incorporation into design (Aromaa & Väänänen, 2016; Braatz, Toledo, Tonin, Costa, & Menegon, 2011; Gatto, Mól, Luquetti Dos Santos, Jorge, & Legey, 2013; Lawson, Herriotts, Malcolm, Gabrecht, & Hermawati, 2015; Lawson, Salanitri, & Waterfield, 2016).

Virtual reality and augmented reality environments can be created and deployed using commercially available software designed primarily with the intent to develop game applications. These software packages known as Game Engines (GE) provide a set of preprogrammed tools (e.g. complex interactions programming, advanced AI physics and rendering capabilities, high quality graphics and virtual reality environments development, etc.) for designers to build their own applications more easily. GE have been used in several areas such as education (Hamari et al., 2016; Koops, Verheul, Tiesma, de Boer, & Koeweiden, 2016), personnel training and knowledge management (Allal-Chérif & Makhoul, 2016; Aziz, Chang, Esche, & Chassapis, 2015; Kwon & Lee, 2016) and facilities simulation and design (Braatz, Toledo, et al., 2011; Gatto et al., 2013; Koutsabasis, Vosinakis, Malisova, & Paparounas, 2012).

Game engine-powered virtual environments (VE) have intrinsic affordances that can be appropriated and applied to the field of E/HF such as their integrated support for 3D visualization, simulation environments, real-time navigation and manipulation of objects and environments, user embodiment and feeling of presence (Koutsabasis et al., 2012).
RESEARCH OBJECTIVE
In this context, this paper aims to explore how game engines can be appropriated by ergonomists as a tool to support the analysis, validation and design stages of work systems’ design process and ergonomics interventions.

METHODOLOGY
Two virtual environments were developed using game engine technology: one representing a real situation in a local control room in an oil refinery industry and the other a fictional industrial scenario. The development of the scenarios was guided through four major axes: “virtual environment”, “digital human”, “interaction” and “analysis” as shown in Figure 1.

The virtual environment dimension presents the most usual possibilities for creating a scenario in a GE. Designers may use existing 3D CAD (computer aided design) models they develop themselves or look for suitable models in comprehensive online libraries such as Sketchup’s 3D Warehouse. The information intended to be communicated through the virtual environment must also be considered when selecting the 3D models and spatial distributions in the scenario. The digital human dimension highlights the needed considerations when creating and deploying the characters that will populate the virtual environment. Anthropometry and biomechanical aspects must be considered when modelling and animating the characters, which can be achieved through movement capture (MoCap) technologies, or other similar tools. The interaction dimension relates what are the possible actions the user can perform in the VE and their immediate results to the environment and other characters and components of the system. Analysis are enabled by previous three dimensions presented, being qualitative or quantitative in its nature, according to the specific objectives aimed at the VE design.

These dimensions are interdependent, and the relevant aspects of its relationships are presented in Figure 1 along the edges of the main diamond shape. Analysis focusing on the digital humans represented in the VE will pass through reach and access analysis, field of view and mannequins postures’ and actions. On the other hand, analysis on the spatial environment built in the GE will focus on its physical layout, environmental conditions (lighting, noise, etc.) and relevant design variables. Similarly, interactions on the VE may focus on scenarios changes, objects, equipment movements and layout modification, as well as information gathering about the overall system depicted in the GE. Defining how users will navigate and experience the VE and the possible interactions with other players (multiplayer support), with non-player characters (NPCs) programmed to perform certain actions or even powered by sophisticated AI are also necessary steps for VE development.
Figure 1. Conceptual framework for GE-based ergonomics visualization and simulation

The first step of the development of the scenarios was the selection of the GE. There are several commercially available GEIs, the most well-known ones being Unity 3D and Unreal Engine, both being free to use for personal projects. In our case, we chose the latter due to the authors’ familiarity with Unreal Engine and its better off-the-shelf graphics settings and visual programming solutions. The development of the 3D characters used Adobe’s Fuse CC software, which allows for great customization of the characters and integration with animation databases (such as the Mixamo library also used for the animations) and GEIs in general.

The authors designed the 3D models of the first scenario on traditional CAD software (Autodesk’s AutoCAD), retrieving some specific pieces of furniture and equipment from the 3D Warehouse models’ library and other free assets libraries. Assets downloaded from the 3D models’ libraries mostly composed the second scenario.

Hardware requirements for GE utilization are robust. The computer used in the development of the scenarios had an Intel i7 4700HQ processor, a dedicated GTX 860M graphics card and 12 GB of RAM memory.

RESULTS
The first scenario developed aimed at representing a real work system in a VE. The goal of this VE was to enable users to explore the environment and through their interactions with NPCs (dialogues) and with objects and equipment, to achieve a better understanding of the issues existent in the represented workplace. Figure 2 shows two snapshots of the VE developed.
Users could navigate the scenario in a first-person point of view, using either a computer keyboard and mouse or a standard Xbox 360 controller, with or without cable. Interacting with characters or objects was achieved by either pressing a preset keyboard key or joystick button, or by pointing the cursor over interaction points. Dialogues with employees’ characters were designed based on real operators’ verbalizations. Relevant information about organizational aspects (e.g., the information exchange among shifts using the white board) was presented interest points.

The second scenario, aimed to represent a fictional industry setting providing users the freedom to explore the environment in a multiplayer setting, based on local area network. Users could also interact and change the layout of the production floor, from a process layout to a manufacturing cells layout. Figure 3 shows the second scenario developed with six players’ characters in the VE.

**DISCUSSION**

Due to its intrinsic characteristics reported by (Koutsabasis et al., 2012) and verified in the VE presented, GEs have the potential to could be a powerful tool to ergonomists and designers. Drawing back from (Güérin et al., 2001; Wisner, 1995) we propose a schematic model of GE utilization in the ergonomics intervention process, shown in Figure 4.
The conceptual model of the ergonomics intervention process depicted in Figure 4 chronologically positions the validation moments in the intervention. Validation of the analysis and diagnosis of the current situation, spans until the beginning of the design of the proposed solutions. At this point, validation focus changes towards the solutions being proposed and after the conclusion of these solutions, a final validation is required to assess the effectiveness of the ergonomics intervention process.

Similarly, the first moment GEs can be employed in the ergonomics intervention is in the analysis stage of the current work situation. By providing a visual platform where ergonomists input their insights from the current situation and at the same time validate these perceptions with the personnel from the area, we argue that GE’s visual and graphical affordances make communication and interactions easier, thus presenting a boundary object nature. Furthermore, throughout the design phase of the intervention, ergonomists, designers, engineers and workers may use GE to simulate and discuss about different configurations and future scenarios, creating new concepts and alternatives. The role of GEs in this stage would be more in line with (Vinck et al., 1996) open intermediary object, due to its concept generation and iterations support. Finally, after a design solution definition and even before the implementation of the solution, the GE can be deployed as a tool for training personnel in the new work procedures proposed. The communication and “getting to know” the chosen future scenario span throughout its implementation takes GE’s role towards a closed intermediary object (Vinck et al., 1996).

Nonetheless, it could be a challenge to develop a GE-powered virtual environment once it usually requires skills in 3D modelling, animation and programming and is a time-consuming endeavor. Multi-disciplinary teams would be necessary to fully realize GE potential for ergonomics.

The analysis GE-based VE allow are not to be compared to those performed in traditional DHM software, since the latter are specialized solutions for very specific issues, mainly in the analysis of current situations. However, if necessary, GEs could support more refined postural and biomechanical analysis through the implementation of algorithms and scripts to perform the required analysis. The differential of GEs lies mostly in its high-end graphical visualizations and interactivity which allows for the creation and simulation of complex scenarios and work systems, enabling it to be used both and analysis and design tool.

CONCLUSIONS
Acknowledging GEs as a knowledge object which can foster communication and collaboration during the analysis, validation and design stages of an ergonomic intervention is an expected
step towards the continuous development of tools and techniques that empower ergonomists to achieve the ergonomics' dual outcome of assuring workers' well-being and performance.

Furthermore, it could be interesting to follow closely the development of GE technologies, once the gaming industry operates with a multi-billion-dollar budget and there's always new features being released (e.g. virtual reality/augmented reality support). Limitations of the technology such as the absence of native, high fidelity, digital human modelling tools which consider anthropometric and bio-mechanical can restrict the range of analysis conducted with GEs. For strengthening the integration of ergonomics into the design processes we suggest further research on how practitioners and researchers may use novel technologies in the ergonomics intervention process.

REFERENCES


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