10IDM-0063

Bridging Car-Design and Engineering: Evolving Towards Immersive Virtual Reality Environments

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Author's Final Draft

ABSTRACT

The development of a concept vehicle from a blank slate to a prototype functional car involves a large number of multidiscipline collaborative professionals. In particular, the transition of the conceptual design to a fully working prototype is typically affected by untimely delays due to the complex communication avenues existing between car design and engineering teams. The paper investigates a novel method which aims to engage the involved teams in a constructive exchange of information and ideas which could potentially result in faster completion of the concept to the prototype stage. In order to evaluate the proposed system, we conducted a comparative study between the concurrent methods and the proposed immersive Virtual Reality system, with the participation of ten users representing both professional categories. Overall the paper presents the current inter-disciplinary collaboration obstacles, elaborates in the proposed solution and discusses the initial evaluation findings, offering suggestions for further investigation and a tentative plan of future work.

INTRODUCTION

Concept vehicles' car-design and prototype engineering are typically the most essential parts in the development of new vehicle models. Traditionally, highly skilled designers and illustrators create a plethora of design proposals and explanatory sketches, with a view to distilling these to a complete concept. In order to improve the flow of information, a "design package" with dimension information is typically provided so as to guide the car-designers towards more feasible designs. Additionally, clay-modelling has been adopted as an initial three-dimensional visualisation method which could improve designer's spatial awareness with regard to their production volume and shape.

Yet the conveyance of this information to the engineering groups can be hindered or delayed by design inaccuracies or untimely alterations during the development process. Conversely depicting manually, every single detail of the vehicle shape and structure is a time-consuming effort which can cause delays and frustration in the involved teams and can affect the overall cost of the development process. Although this method is still in use, advances in computing and 3D visualisation techniques presented new ground for developing vehicle prototypes and gradually have been infused in the development flow [1, 2, 3].

Even in digital format though, the data representation is predominantly presented in 2D monitors that do not allow the developing teams to investigate the volumetric and structural efficiency of their designs, in a real three-dimensional space. In this vein, we designed a common testing ground for both developing groups, which could improve the exchange of structural and design alterations in real time through a virtual reality environment [4].

For evaluation purposes, a non-branded concept vehicle was designed and modelled with CAD software in order to be utilised as an assessment model for the virtual environment (i.e. shape, structure, mechanical components), namely AutoEval system [1, 4]. Furthermore, the AutoEval virtual-reality environment was customised accordingly in order to offer a large variety of interactive tools with the 3D model. The virtual model was presented in life-size dimensions so as to increase the realism of structures under investigation.

Initial trials showed that the use of augmented reality and custom human-computer interfaces has significantly enhanced designer's perceptual and cognitive understanding. Furthermore, mechanical-components could easily be fitted and reform the exterior mesh around them. Evidently, this approach suggests that the evolution of virtual environments could extensively support faster and more efficient concept-vehicle development, complementing at the same time the traditional illustration methods [5, 6, 7].

As the initial results were promising, we are particularly keen to develop additional interactivity which will enable non-expert users in CAD to modify design parameters in real-time using a virtual-reality-based interface and receive immediate feedback from simulations and design rule inspection systems [9, 10, 11]. Finally, the paper further outlines the evolution of the system design as a result of ongoing evaluation and user trials and offers suggestions for further research and a tentative plan for future work.

CONCURRENT BRIDGING ISSUES

Simplification of tasks and communication amongst different collaborating groups towards the development of prototype vehicles has always been a hindrance to faster vehicle research and development. Advances in computing in the last decade offered the capability to minimise significantly the development and production time. Evidently a number of automotive companies invested in the employment of technological solutions which enabled them to visualise and produce prototypes in a significantly faster pace. In turn, the utilization of emerging technologies dramatically decreased the development of prototype vehicles from a blank canvas to a fully functional prototype state[12].

Yet the brainstorming and conveyance of its results is still largely an issue between the conceptualising teams and the implementation teams. This occurs as the main means of design and development are based on two-dimensional methods and systems. Hitherto, the 3D vehicle prototype is typically presented in a monitor designed with the use of CAD software. However, the deliverable in the monitor is a misconception as the model is depicted through a 2D computer screen. As such it doesn't provide the developers with the real spatial and volumetric information required for the actual evaluation of vehicle shape, volumes and mechanical and electrical vehicle components [13]. As mentioned above the clay models in scale offer a better approach to these issues, but their limited usability and time-consuming development do not effectively support the whole process. Furthermore, any imminent alterations proposed by the participating teams could not translate equally rapidly to a visible result. In addition, the number of involved users in such development can be significantly limited due to the size and interactivity means. In this paper, we use a generalisation between designers and engineers to encapsulate a number of involved individuals and teams (i.e. human factors engineers, mechanical engineers, electrical engineers, vehicle interior designers, exterior designers, electronic engineers, HMI and HCI developers, and others) within a wide spread of specialities. In real-life, all the participants have to collaborate efficiently and in a timely manner in order to produce a successful product. Adhering to the above issues and appreciating the diversity amongst and within professional teams we have developed an all-inclusive prototype interface which utilises a Virtual Reality environment to visualise and interact with a concept vehicle.

RATIONALE

These types of issues are typically identified as a part of an iterative process in which designs are being evaluated and improved. This work focused on the de-mystification and simplification of this process through the use of off-the-shelf components. The visualization and simulation in a 3D VR environment of the concept design can offer to the car-designers and engineers an early stage appraisal of the prototype vehicle. Such insight could drastically reduce the ergonomic errors in the very early stages of the design process. Moreover, in such a multifaceted system optimization of the aesthetic and ergonomic design could be achieved through VR prototyping in a considerably more cost-effective manner than in a complete physical mock-up model [8, 12, 14]. The digital form of the prototype can be customized in real-time and updated in a timely manner. The newly introduced changes can be reviewed within the overall context or individually offering invaluable flexibility for multiple alterations in the same model during the development process

Furthermore thought the VR environment the users are enabled to investigate the vehicle’s design and structural elements using infinite viewpoints. The 3D data manipulation could further be examined with the use of a large number of haptic, visual and auditory interfaces as presented in the following section.

EVALUATION RATIONALE

Drawing from our previous research in the field we employed a combination of software and hardware in order to present in a Virtual Reality environment the 3D vehicle model. Concurrent endeavours in the development of photorealistic digital modelling and multimodal interactive environments have fostered the development of complex structures with minimal cycle time and implementation costs during the development process [4, 5, 15, 16]. Real-time visualisation in this context is used as a powerful means of communication within the involved teams or to external collaborators. To facilitate this we opted for a large projection area which was critical to enable group discussions and interaction with the 3D model, as described analytically in the following sections

HARDWARE

The VR environment developed for our experiment included a large scale stereoscopic projection that offered life scale visualisation of the vehicle and enabled the users to better understand the volume relations. This was achieved with the use of a high-resolution widescreen (2800 x 1050 pixels on 4.4m x 1.65m). All the display devices were driven by PC workstations with dual Quad-Core Xeon processors and Nvidia Quadro FX4400 graphics hardware. Whilst the above display systems can produce superior quality visuals, the experiment presented in this paper could also be run successfully on less expensive hardware combined with a medium range projector.

SOFTWARE

The 3D vehicle model was developed in a CAD program (Maya) and was re-introduced in the Virtual environment through a VR simulation suite (i.e. VEGA). The real-time tools were developed around the platform offered by Presagis (formerly Multigen-Paradigm) including Vega Prime for the real-time simulation and Creator for model preparation.

INTERACTION DEVICES

During the development of the interface for the VR environment, we investigated various options based on our previous experience in HCI development [1, 2]. In order to minimise interference to the task from the actual system, the interaction should follow fluently the user's commands and should be easily understandable, so that the user's attention is not diverted. Notably, the interface of such a conveyance system should be able to facilitate the needs of even novice users. Holding on to these observations, it was deemed essential to have clear and simple visual and auditory cues. In turn, the interaction and management of the 3D data were designed based on direct-manipulation mantras previously tested [1, 2, 3, 5, 8].

In particular, manipulation of large datasets, like a vehicle design, requires fast and flexible interaction tools and devices which can enable the user to investigate the model without being absorbed in complicated menus. To this end, we equipped the space with devices that could enable the user to navigate in the 3D space using either haptic gloves with tactile feedback, or more conventional systems such as joystick, mouse, trackball, console pads (Xbox, PlayStation) or a combination of a 3Dconnexion SpacePilot ("3D mouse") for navigation and a joystick to control the additional customised parts as depicted in Figure 1. For implementing such hands-on interaction paradigms it was required to employ 3D tracking sensors for the VR model to follow the hand and head movements of the participants.

LEVELS OF INTERACTIVITY

Defining the levels of interactivity in such large data sets and objects is essential, as any unnecessary complexity might discourage the users and render the proposed system unusable.

Valuing interactivity as a key factor for the success of our system we invested heavily in the development of interaction avenues between users and system. Yet the photorealistic visualisation and presentation of a vehicle's 3D model can be considered preferable. Although the visual quality does not fully approach that of a dedicated 3D software renderings (Maya), mainly concerning lighting effects, shadow and car-paint glossiness, real-time rendering can produce a decently realistic impression of the 3D model. Furthermore, the real-time system enables the natural reaction to requests from the users. However, unconstrained interactivity with the data might again hinder the effectiveness of the system

Hence, we created three generic levels, namely: entry, medium and experienced level. On the entry level of interactivity, the virtual environment allows free control over time, enabling the users to set the pace of a review or presentation session. The medium level enables users to investigate the model through a free viewpoint and motion control. This additional capability allows the users to inspect any part of the design from a range of angles that may not have been foreseen during the planning of a review session. The navigation can be achieved either by viewing the model through a completely free viewpoint or by a preset range of viewpoints. Selection and navigation can be implemented through Joystick, control gamepad or SpacePilot device. The experienced user level accommodates various tools such as transparency, cross-section, volume manipulation, the dismantling of parts, colour alteration and other functions. The most important feature unlocked in this stage however, is the data manipulation with the use of a haptic glove, which allows the user to manipulate data by literally grasping it. In the beginning, this might seem an awkward method of interaction, yet in a very short time, the users find it very involving and easy to use, as it enables them to move away from typical interaction devices (i.e. mouse).

In this level, the cross-section tool is also very useful, as it interactively places a cut-away plane in any possible angle, enabling the user to look inside the design. This can also be dynamically positioned with the glove allowing interactive “removal” of parts of the design until gradually the inside structures are revealed without loss of the context information. To this point, it has to be noted that during the development of the 3D vehicular models we typically equip the data with a range of switches to toggle the visibility of key components or layers between visible, semi-transparent or hidden. The transparent function is particularly interesting when multiple module positions must be shown simultaneously within the context [1, 8, 12].

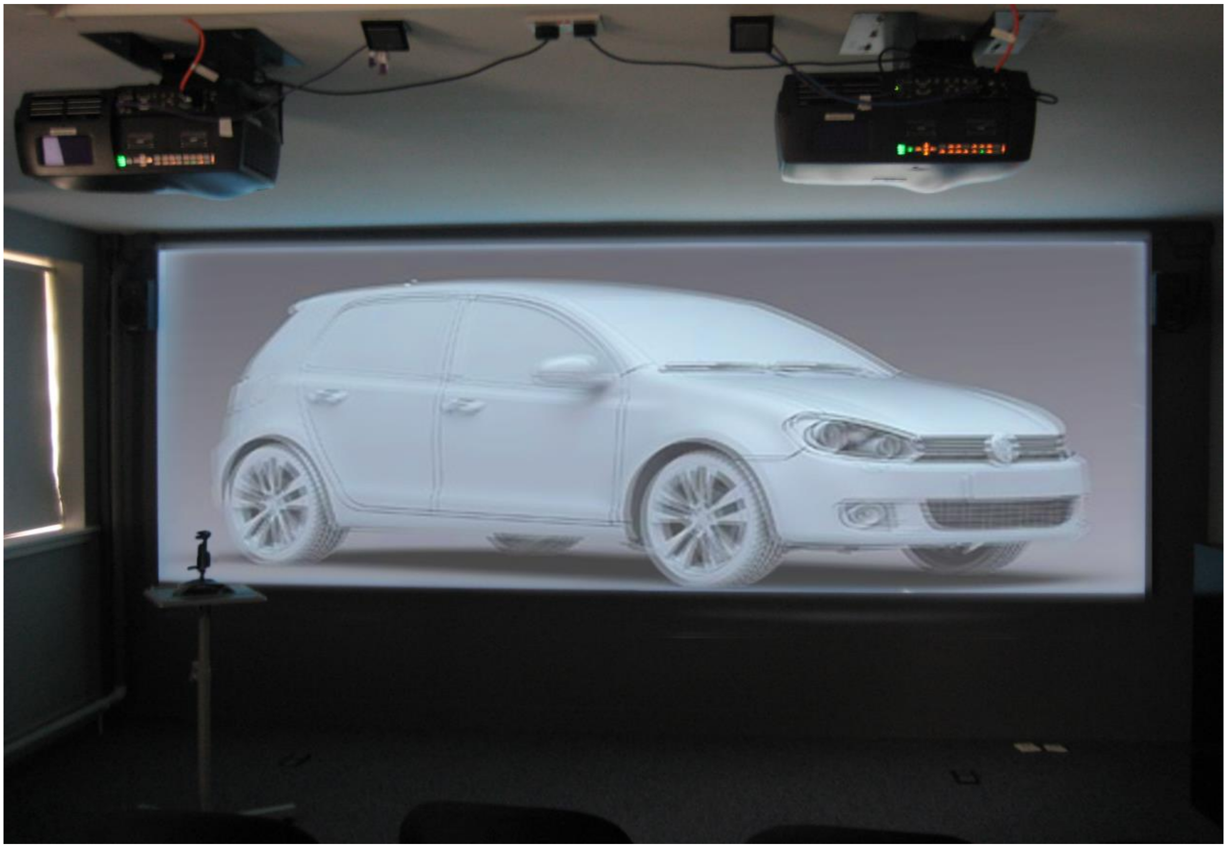


Figure 1: Full-scale vehicle stereoscopic projection

SCENARIO

A prototype conceptual design and implementation entails a process in which the participating groups inevitably are challenged to take some detailed decisions, albeit tentatively. Primarily this information is provided by the "design-package" which yet can be utilized or interpreted differently from each group.

In particular, the two groups that typically are in friction are the concept car-designers and the prototype engineers. Being aware of the communication issues that might arise during such exercise, we challenged their communication abilities by offering an incomplete prototype vehicle and three design and structural options for each major moving external part (i.e. doors, bonnet, trunk) and three different versions of engines as illustrated in Figure 2.

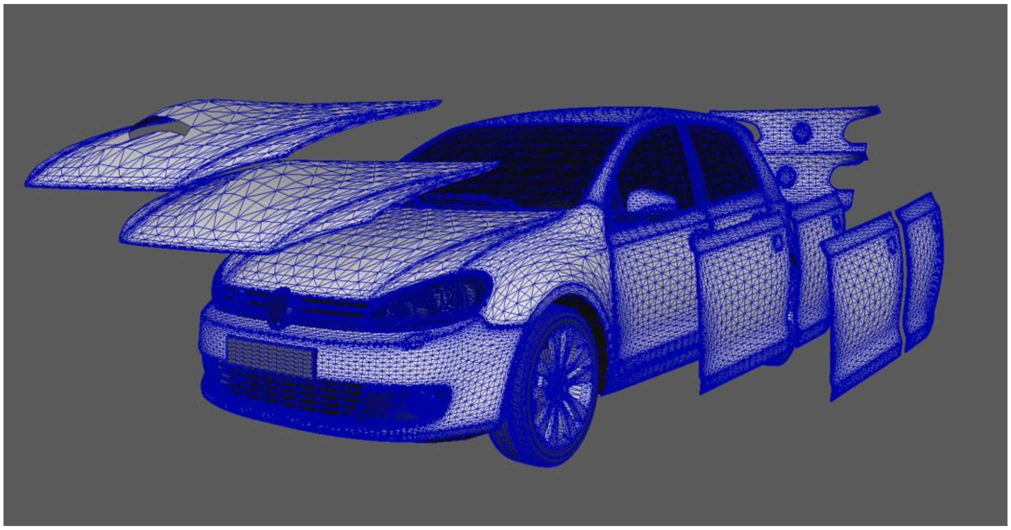


Figure 2: Vehicle design and options

This restriction of options was deemed essential for the evaluation of the proposed system in a controlled and measurable environment. Furthermore, the design and development of a vehicle from blank canvas would be an exceptionally time-consuming process which was not the aim of this experiment. In order to have an appraisal of the systems ability to convey effectively the information between the two categories of users, we designed a comparative evaluation between the traditional means of collaboration between car-designers and R&D engineers. The experiment process was divided into two sections presented analytically below:

PART 1

In the first scenario, we presented the vehicle 3D model in a CAD environment to the designers. Purposely, the prototype vehicle had some design flaws. The designers had to discuss with the engineers the potential solutions, their benefits and drawbacks. Their task would be completed as soon as they could agree in the actions that should be taken further for the development of a complete vehicle.

PART 2

In turn, the same prototype vehicle with minor alterations was used to spark a discussion between the two groups. In this second trial, the users utilised a Virtual Reality environment where they could see and interact with the vehicle in real-size. Additionally, a custom Human-Computer Interface was developed in order to accommodate this exchange of ideas.

METRICS

In order to evaluate the derived data and identify the efficiency of the proposed system in contrast to the existing collaborating methods, we introduced some qualitative and quantitative metrics. As such the primary metric was the estimation of time that was required for the teams to reach an agreement in the vehicle design and complete any necessary alterations [17].

The subjective feedback was collected through pre and post-trial questionnaires which were aiming to reveal user's satisfaction with regard to the interface design, interactivity, realism in visual representation and ease of information conveyance. In particular, the post-questionnaire was formed through ten questions where the users we asked to respond in a scale of 1-10 (1 the lowest). These questions were split into two areas of interest with the first five to investigate the effectiveness of each method to convey information (VR vs Traditional). The second group of five questions aimed to investigate the acceptance and drawbacks of the interface for each method as presented in Figure 3 below.

EVALUATION RESULTS

The contrasting approach between the current methods and the proposed VR offered intriguing results which were strongly in favour of the latter. The VR system was perceived as a very fluid and clear method to convey information and favoured an intuitive interaction with the data set as depicted in Figure 1. The traditional method of communicating the design ideas was generally characterized as insipid and unpractical, as it failed largely to facilitate the input of both teams.

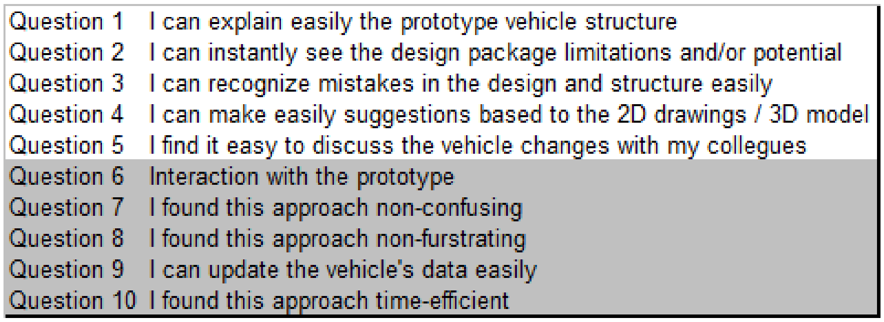
The results of the user questionnaire highlighted the VR interface's ease of use as the users found it less annoying or frustrating than interpreting two-dimensional images in paper or CAD environment. As the groups had little previous experience of VR, the authors had some initial reservations with regards to acceptance of the unusual VR interactive environment.

These reservations were dispersed during the trials, as the users became easily accustomed to the environment and the interactive devices. Overall the proposed system was utilized effectively, enabling the participants to manipulate the 3D data and readily adjust their viewing position and the customised sections displayed in an intuitive and timely manner via the console.

STATISTICAL ANALYSIS

An initial appraisal of the results could be seen directly by the time-differences produced during the trials with the traditional and with the VR method. Evidently, the use of traditional methods to discuss a specific model, potential alterations and conclude to a completed prototype reached approximately 165 minutes (2h and 45m). Even though it doesn't appear to be a very lengthy process it was significantly longer than the 45m approximately that the team spent in the VR environment in order to achieve the same result.

Although this was a very strong indication of the VR interface and overall system supremacy against the traditional methods we were more intrigued to identify the impact of each method in the individual's process of communicating their ideas. To this end, the following analysis of data presents the benefits and drawbacks of the proposed system towards bridging car-design and engineering.



Question 1	I can explain easily the prototype vehicle structure
Question 2	I can instantly see the design package limitations and/or potential
Question 3	I can recognize mistakes in the design and structure easily
Question 4	I can make easily suggestions based to the 2D drawings / 3D model
Question 5	I find it easy to discuss the vehicle changes with my collegues
Question 6	Interaction with the prototype
Question 7	I found this approach non-confusing
Question 8	I found this approach non-furstrating
Question 9	I can update the vehicle's data easily
Question 10	I found this approach time-efficient

Figure 3: Post-trial questionnaire and groups of interest.

The data analysis of the mean scores for each question, for designers and engineers, presented a clear preference towards the VR interaction method as presented in the following Figures (4, 5).

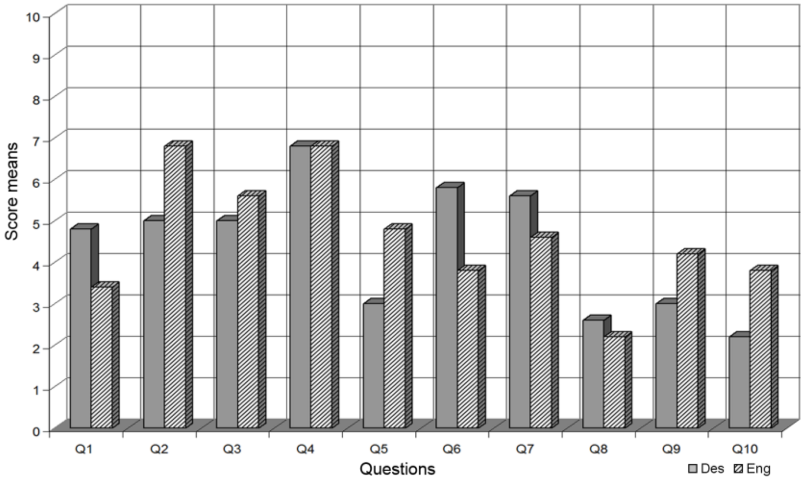


Figure 4: Mean scores for designers and engineers using the TR (traditional) method.

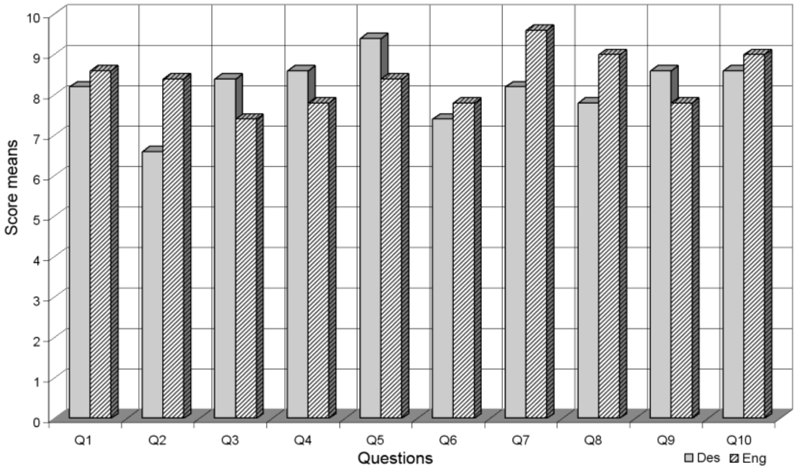


Figure 5: Mean scores for designers and engineers using the VR (Virtual Reality) method.

In order to identify if the derived responses would reflect the vast majority of the car-designers and engineers we employed a statistical analysis method namely “independent samples test for equality of means”. With this method, we seek to measure the existence and the degree of agreement between the two groups, so as to clarify the effectiveness of the proposed system over the traditional way of communicating and depicting their ideas and suggestions. The inference is estimated with a 95% confidence level to be applied for the population of both designers and engineers. Notably, the variances are not assumed equal. In particular the Sig. (2-tailed) column presents the means of responses for both groups. In case that the mean is larger than 5% the formula estimates with 95% confidence that the score means from both user groups could be extrapolated to the whole population of the car designers and engineers. In contrary any value smaller than 5%, the mean scores of designers and engineers for that question will not reflect the opinion of the whole population, with 95% level confidence. A manifestation of depict responses that could be perceived as true for the whole population is depicted in Figure 6 and 7.

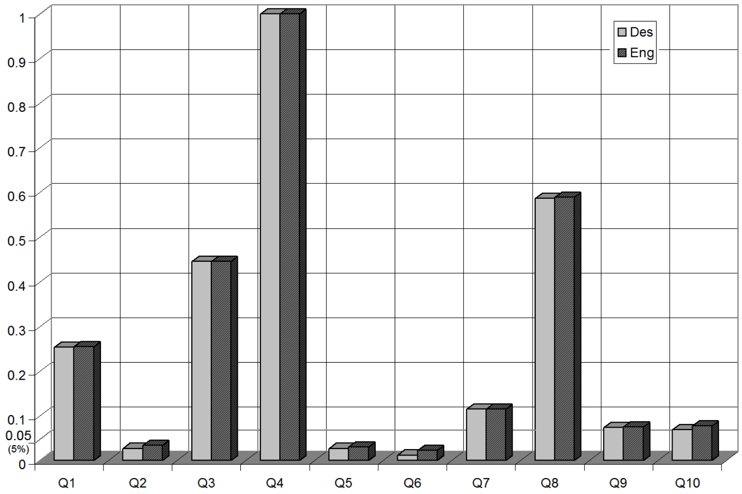


Figure 6: Extrapolation of results in the population: Percentage of mean scores for designers and engineers using the TR (traditional) method.

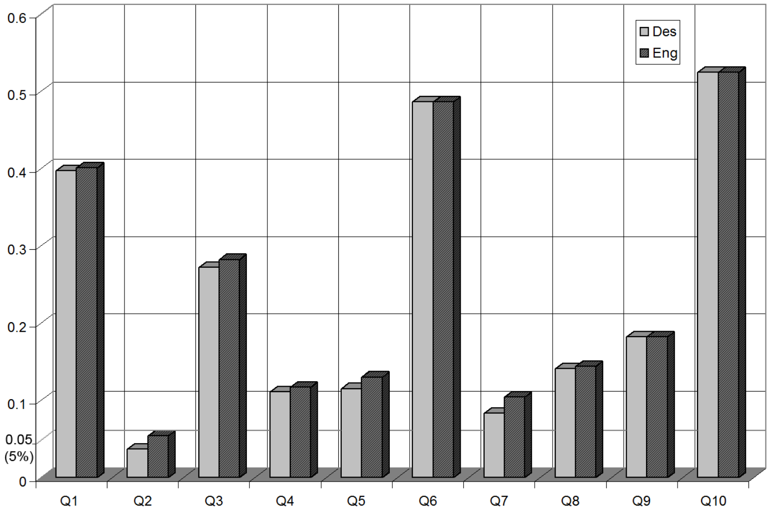


Figure 7: Extrapolation of results in the population: Percentage of mean scores for designers and engineers using the VR (Virtual Reality) method.

Three responses though for the traditional method (TR) did not appear to apply in the majority of the involved users (Q2, Q5 & Q6). This result could be potentially clarified in a future experiment which will involve a larger number of participants as the responses to these questions were quite difficult to predict in this particular small sample of subjects. Interestingly for the VR method, almost all the responses except from one can be extrapolated to their whole population for both groups. Concluding the trials the derived interviews with both teams highlighted the fact that the VR environment was exceptionally useful to examine and pinpoint any suggestive alterations on the vehicle design and structural details. Notably, the interface offered the ability to switch between the different suggestions, so as to enhance the understanding of the spatial positioning of the custom or altered components.

CONCLUSIONS

This paper presented an endeavour to bridge car-design and engineering with the use of emerging technologies employed through immersive Virtual Reality (VR) environment. The latter was designed, based on prior extensive research in HCI and VR environments.

An indicative estimation of the potential benefits and drawbacks was derived through a comparative study which contrasted the existing traditional methods of communication between design and engineering teams with an experimental VR method. The time consumed in order to complete a simple development task in a concept vehicle was significantly decreased with the use of the VR system. The results could reflect a large portion of the professional population of both groups, yet some of their responses require larger user trials, for the population attitude to be elucidated in full. This discrepancy could be coined to the different talents and dexterities that these two teams are using in order to convey or present their ideas and suggestions. To this end, the VR interface managed to attract favourable comments as it is clearly illustrated in questions 6-10 in Figure 5. Overall the users seemed to consider the system positively and showed a willingness to adopt it as the means for information and ideas conveyance in their professional environment on a daily basis.

Nevertheless, setting aside the initial encouraging responses it is obvious that the appropriate development of an inclusive and simple to use system requires additional evaluation with regard to the subjects' numbers, trials and different design scenarios.

Consequently, it is on our future plans to improve the HCI functionalities and expand on more all-encompassing interactivity with the use of similar interface in an Augmented Reality environment, enabling a wide range of involving professionals to contribute their suggestions in a non-disruptive manner.

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