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The Importance of Virtual Immersion in the Rapid Prototyping of Industrial Products

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Abstract: The prototype has played a major role in the design of industrial products since the beginning. The series production was never launched until the designers validated the new product by studying in detail a prototype made identical to the ones that would have come out on the tape. Rapid prototyping, especially through 3D Printing, for small and medium-sized products, managed to improve this design phase by the quality of the prototype obtained and by the short times of its realisation. Recently, virtual immersion tends to replace 3D Printing technology (or work together), the prototype made by this technology offering the designer many more features of the designed product. As a concept, Virtual Reality Aided Design (VRAD) significantly reduces production times, costs and especially allows the rapid modification of the prototype, which is impossible to achieve in 3D Printing. Our article presents the study of a Compressed Air Vehicle (CAV) prototype participating in the international academic competition PNEUMOBILE; it is a study carried out by the UPBAIR team of UPB through virtual immersion. We believe that the study can be extended to the prototyping of any industrial product, adding that our CAV prototype is quite simplistic and quite far from the complexity of a series car.

1. Introduction

The design of industrial products today is an intense challenge for engineers. In this process, it is mandatory to comply with the strict rules imposed on the creation of a high-quality product, environmental requirements, requirements related to the use of new and cheap materials, traceability rules and requirements for life cycle management (LCM) compliance. All these rules turn industrial production into a competition that once lost, can lead to the market exit of the manufacturer [1, 2, 3]. The verification of the designed product by creating a 3D virtual prototype or even a physical one is also a significant challenge for the design team.

For a long time, the automotive industry has stood out as one of the most dynamic industries, one that imposes increasingly restrictive design standards for increasingly shorter implementation periods. The PNEUMOBILE competition (organised annually in Eger, Hungary by AVENTICS and recently taken over by EMERSON), even if it does not stand out as being an activity related to the series car industry, can be included in the category of activities regarding design and production of car prototypes, useful for the near future.

2. Technical framework

The creation of a new product is closely related to creating the prototype, which is absolutely mandatory in developing any category of industrial products. Although the design process can look like any other, from the idea to create a complete concept to design and prototyping, there are also other considerations related to subsequent operation procedures. Regardless of the type of industry, from car parts to aeroplane components, the essential elements of the process of designing and



producing original equipment will generally be the same. In the car industry, the Original Equipment Manufacturers (OEMs) strongly collaborate with new technologies to develop better and better solutions for future cars as quickly as possible.

In general, eight stages are covered by the OEM, from design to the final product [4]. The attention increases for all the problems specific to each stage. Many car manufacturers pay special attention to modernising prototyping in the PDP (Product Development Process). Thus, we find growing interest about the implementation of these technologies via OEM at major companies such as Ford [5], Jaguar - Land Rover [6], Volkswagen [7], BMW [8] and Volvo [9].

For some time now, new methods of rapid prototyping have been helping to launch new products. 3D Printing is an almost indispensable stage in the design of small and medium-sized parts/assemblies. As a new preliminary stage to the physical prototyping, immersive virtual prototyping is also noticed, through the widespread use of AR/VR/MR/XR technologies. This completes the virtual prototyping, generally known as 3D CAD modelling. In this article, we try to show the importance of virtual immersion through Virtual Reality Aided Design (VRAD), as a standalone tool that can even replace 3D Printing or work together with it in the PDP [10].

With the advent of VRAD in the design of industrial products and especially in automotive, the PDP concept has undergone several changes that have led to the simplification of the process [6]. With the introduction of VRAD, the number of stages within the PDP decreased, and certain stages that were regularly used in the physical and/or CAD realisation of the prototype were replaced. Thus, according to [11] new milestones appeared, replacing or joining the old ones:

- *Digital Styling Process* and *Virtual Prototype* (instead *Project Planning and Controlling*),
- *Virtual Seating Buck* and *Digital Data Control Model* (instead/near *Data Control Model*),
- *Digital Mock-Up* (Design/Computation/Electronic Components),
- *Virtual Assembly* (instead/near *Tests & Type Tests*),
- *Virtual Hose Laying* (instead/near *Production/Logistic Concepts & Priority Controlled Releases*) [11].

Many authors, consistent with large car manufacturers, believe that for essential stages of the

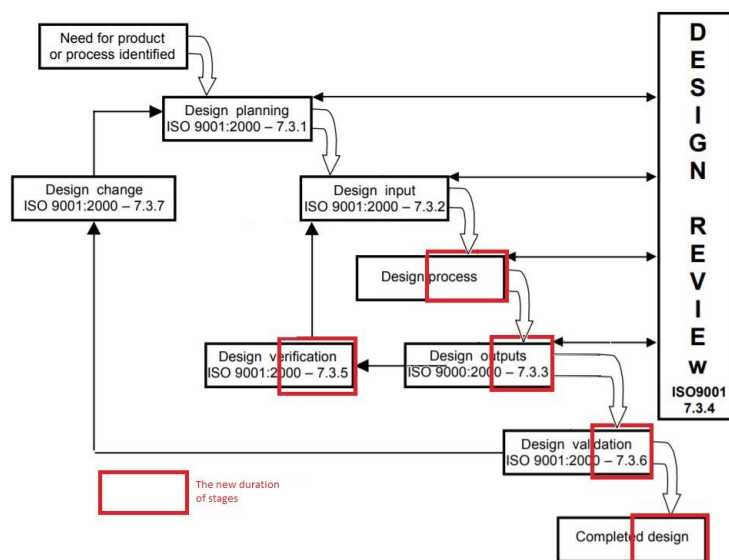


Figure 1. The impact of VRAD on PDP [12, 13]

Design Review process (IEC 61160) working times are substantially reduced using virtual prototyping (figure 1) [12, 13]. We are talking about *Design Verification*, *Design Process* (which brings essential time savings), *Design Output*, and *Design Validation*. The shortening of the duration of these stages also leads to the shortening of the *Completed Design* stage [12].

Virtual prototyping began in the 1980s with the first CAD software packages. However, CAD activity became strong when computing power increased, and graphics and video capabilities benefited from the support of new

technologies. Thus, after 1990 the success became visible by decreasing the working hours and increasing its quality and diversity, offering significant chances for competitive engineering [11]. At the same time, the need was felt for "more" in terms of the analysis of the virtual prototype obtained through 3D CAD. Thus, the VR technology was used, which had also already appeared in 1975 in a form quite close to that of today [14].

The first activities to use VR in the industry appeared at Volkswagen (1994), but in the meantime, other important manufacturers in the car market have included VR in their design work [7]. “Virtual reality helps car designers to be much faster and more precise in developing new vehicles. What used to take months and needed to be tested as a physical prototype model, we can now speed up with virtual reality”, says Marek Polcak, trying to stress that VR technology can be more than useful for automotive industry [15].

Now, in 2021, it can be said that VRAD is still not a perfect tool in the PDP. A recent study asked stakeholders about the use of VR in design and engineering activities in the automotive industry, especially about the level of human interaction with virtual products in immersion conditions [2]. The results of the study revealed some problems related to the use of both physical and VR processes. Regarding the VR systems recently used at Jaguar Land Rover, for example, stakeholders reported some hardware issues (e.g. HMD weight, body tracker suit difficulties), some software issues (e.g. depth perception issues, colour rendering) and problems related to dizziness caused by movement in virtual space [2]. Solving these problems is nowadays the concern of all engineers in the field, focusing on improving existing technologies with new tools and features. Many of these shortcomings have been resolved in the meantime, with immersion through other technologies than HMD (eg. CAVE immersion system utilisation) being much more efficient.

In conclusion, VRAD is still dependent on the solving of several problems, and specifically the relationship between artificial and natural. Complete human interaction with the virtual prototype is crucial but difficult to accomplish fully. There are few techniques to do it - technologies, software and human senses' capabilities being only intuitive at this time.

3. From CAD to VR

The prototype designed by the *Upbair*, the team of the University POLITEHNICA of Bucharest, Romania, is an experimental vehicle with a compressed air engine, designed to participate in the competition "PNEUMOBILE".

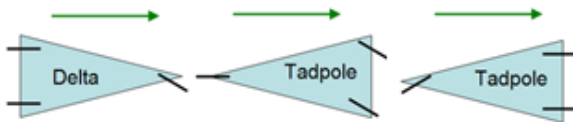


Figure 2. Types of tribike

Because the ancient Roman chariots inspired this prototype design, the vehicle had to use a simple tribike design called delta (figure 2) [16]. The 3D model was created in CATIA and then exported as FBX (figure 3).

Today there are several ways in which we can transfer a 3D CAD model from a modelling application to the final VR application. Moreover, many well-known software packages have started to integrate modules for this type of transfer in recent versions. Due to differences between file formats, many problems arise when restoring the 3D model in VR [1, 16]. Because these reconstruction imperfections sometimes severely influence the final shape of the VR model, intense efforts are being made today to increase the compatibility of CAD and VR file formats.

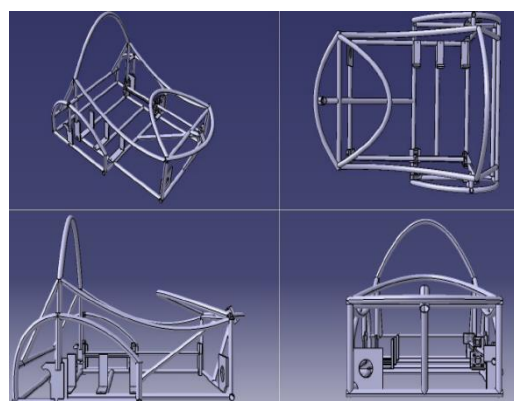
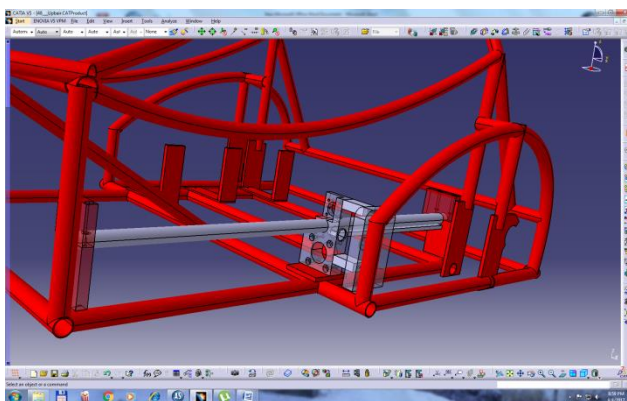


Figure 3. The frame of the prototype modelled in CATIA

There are several simple methods of transferring information from CAD to VR systems, one of the most widely known and used is the one indicated by Zachmann and Gomes de Sa's. The method

uses a Product Data Management (PDM) system as the bus for the flow of data from the CAD system to the VR one. At the same time, it maintains a permanent connection with a Cloud that contains the data about the CAD models, the administrative and technological data, the simulation data and other data useful for the transfer process [1, 17].

In our work, different FBX 3D models have been created for different versions of the prototype, and these models were imported in Unreal Engine Application. During the VR immersion, the user can study different aspects regarding the ergonomics, the proper car size, and placement of different accessories and components in the application. The user can sit in the car and have a real feel of physical presence. In this way, we were able to design an optimal final model in a short time, without creating a physical prototype.

4. Virtual immersion

Immersive Environments for Virtual Reality provide a more natural means of visualising and manipulating data through a more intuitive, spatial understanding, broader and more dynamic information, and more collaborative spaces [18, 19, 20]. The answers to many questions regarding this technology can be found by analysing and evaluating three important and distinguishing factors of the Virtual Immersion Environments: presence, immersion, and interaction. Companies use immersive technologies such as AR/VR/MR/XR, but it will take 5 to 10 years to reach the desired level of satisfaction [21]. After a comprehensive analysis, Christy Pettey notes that "the biggest barrier to wide adoption of immersive technologies is the lack of good user experience design" [21].

Since Virtual Reality provides an immersive and intuitive human-computer interface, it becomes suitable for many studies. We have started to develop the VR application using Unreal Engine, an open-source game development platform. The game engine comes included with an editor for creating scenes based on imported 3D models, materials, characters, and animations. The development of interactions can be done in C++. Programming in Unreal Engine can also be done via Blueprints, by connectable event-driven structured, logical building blocks (figure 4).

The Blueprints Visual Scripting system in Unreal Engine is a complete gameplay scripting system based on the concept of using a node-based interface to create gameplay elements from within Unreal Editor. The most common Blueprint types are Level Blueprints and Blueprint Classes. The Blueprints can also create customisable prefabs with construction scripts, create a playable game character, or create a HUD (Head-Up Display). The Oculus Rift HMD (Head-Mounted Display) was integrated into the application through a plugin-based architecture.

First, a 3D environment was created (figure 5). FBX models were exported from Maya software. The PBR (Physically Based Rendering) materials of models were created using Stingray materials.

The optimisation process using the VR application was relatively easy. CAV component models were exported in FBX format from CATIA software and were then imported into the application. Using the HMD and controllers, the components and accessories were able to be positioned properly. By adjusting the size of frames, "sliding" the chair become possible, optimising the driver position relatively to the engine, gas reservoir and steering system. After a few adjustments of the models, we were able to find the optimal version of the frame's and components' placements, and we proceeded to create the physical prototype of the compressed air vehicle.

After placing all the objects on the virtual stage, the character creation could begin. In the Content Browser, **Blueprint Class** was selected (figure 4). Since it is desired that the actor can receive inputs from the player, the **Pawn** class is suitable (like an avatar). **Pawn** was added from the pop-up window and was named **BP_Player**. Then the camera was attached by clicking Add Component and selecting Camera. The camera was placed above the player.

Before the player can control the **Pawn**, two things must be specified:

- The Pawn class the player will control.
- Where the Pawn will spawn.

A new class, **Game Mode**, has been created that controls how a player enters the game. For example, in a multiplayer game, **Game Mode** can be used to determine where each player appears. More importantly, the **Game Mode** determines which **Pawn** the player will use. The previously

created **Pawn**, called **BP_Player**, has been selected, and a **Player Start** actor has been placed at that level.



Figure 4. Character movement Blueprint

In the Unreal software, one can configure keystrokes that will trigger an **event** when they are pressed. Events are nodes that execute when specific actions occur. When the event is triggered, all nodes connected to the **event** will be executed. This method of binding keys is useful because the user does not have to use hard code keys.

Unreal provides two methods to create key bindings:

- **Action Mapping:** These can only exist in two states: pressed or not pressed. Action events will only trigger once the key is pressed or released.
- **Axis Mapping:** These output a numerical value called an **axis value**. Axis events will fire every frame. They are generally used for actions that require a thumbstick or mouse.

Axis mapping was used, and two axis mapping groups were created: **MoveForward** and **MoveRight**. **MoveForward** handled moving forwards and backwards. **MoveRight** handled moving left and right. For movement, the user has to specify how fast the **Pawn** should move. An easy way

to specify the speed is to store it in a **variable**. In the BluePrint software a float variable, **MaxSpeed**, was created, and the default value was set to 10.

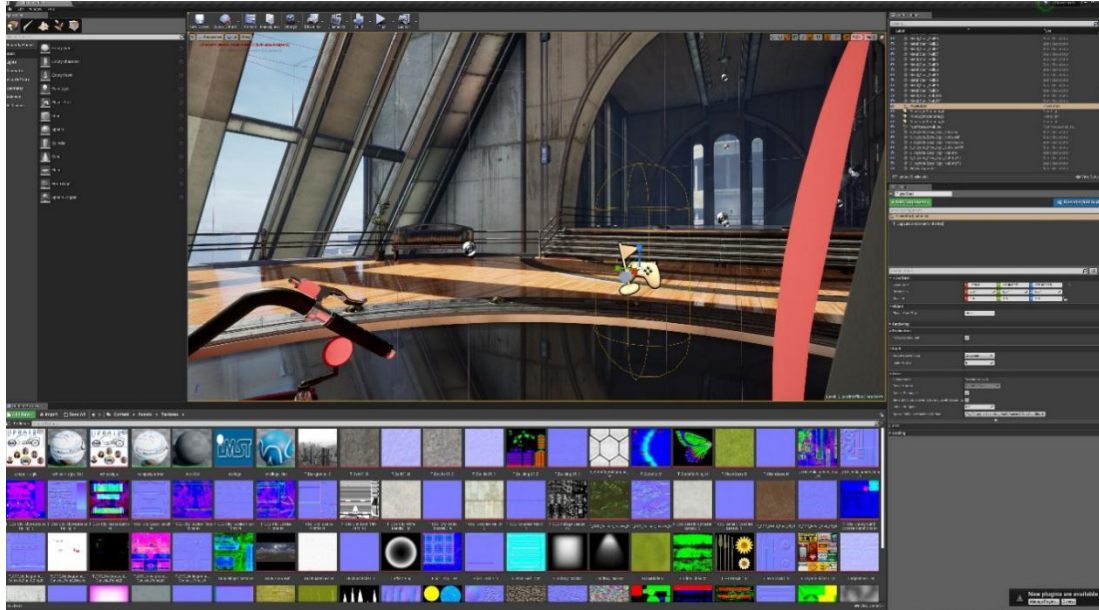


Figure 5. Unreal Engine Project

The **Get Actor Forward Vector** and **Get Actor Right Vector** nodes were used to get the player's direction. Two **Add Movement Input** nodes were added for **MoveForward** and **MoveRight**. These nodes take a direction and receive a value that is converted to a stored offset.

The **Add Movement Input** node takes the following inputs:

- **Target:** set to self, which in this case is the player.
- **World Direction:** The direction to move the target, which in this case is the direction the player is facing.
- **Scale Value:** How much to move the player, which in this case is the max speed multiplied by the axis value (which, remember, is a value in the range of -1 to 1).

To move the **Pawn**, the user must find the offset calculated by **Add Movement Input** and add it to the **Pawn** location. An **Event Tick** was added, and for frame rate independence, the **Delta Seconds** were used.

To collide, an actor needs a representation of its space where collisions can occur. For this, one of the following can be used:

- **Collision mesh:** This is automatically generated when a mesh gets imported. The user can also create a custom collision mesh using 3D software. The **actor** already has an auto-generated collision mesh.
- **Collision component:** This comes in three shapes: box, capsule and sphere, and it can be added through the Components panel. Generally, it is used for the simple collision.

A collision occurs when an actor collision touches another actor collision. To use the collision mesh, **StaticMesh** needs to be the root.

5. Improvements to the prototype through VRAD

The power of VR technology is its ability to fully immerse a user in an artificial environment and build a virtual model according to all the characteristics of the real future model. A good and realistic experience aims to convey emotion and uses synchronisation, space, lighting, sounds and interactions, to create a sense of physical presence in the world that is created. Automotive (and Manufacturing in general) can benefit from adopting VRAD tools & techniques when they are

examined from a problem-solving perspective in the context of the Product Emergence Process [3-18].

In this study, a non-exhaustive evaluation was made of the benefits obtained by adopting VR technologies in the development of the new CAV prototype.

Position of the Centre of gravity (CoG) - With the help of a special car seat built for VR immersion (figure 6), made available by the Image Institute - ENSAM, Chalon sur Saone, France, an institute specialised in AR & VR research, the position of the CoG obtained from 3D modelling with the CATIA software was checked.



Figure 6. The driver checks the position in conformity with VRAD analysis



Figure 7. A special driver's seat used in VR immersion (courtesy of Institute Image - ENSAM)

This CoG is essential from many points of view, like the dynamics of the prototype, the personalisation of the seat fixation according to the driver (figures 6 and 7) and especially the driver position in the cockpit in relation to all the instruments and controls inside. Also, the position of the CoG is important to avoid tilting to the left or right side of the vehicle [22].



Figure 8. 360° visibility from inside the virtual prototype

Optimal visibility - VR immersion offers a unique chance to position yourself naturally inside the prototype without it physically existing (figure 8). Through virtual immersion, the driver can study the quality of visibility, finding out if there are obstacles in the visual field or inconveniences that can obstruct a completely free visual field. The driver can also make assessments on:

- the internal and external structural elements of the prototype,
- the position of the engine and all the equipment installed inside,
- other essential components necessary for better control of the prototype while driving, such as the mirrors' position and orientation.

Colours and design - In designing a CAV, it is evident that all the structural characteristics cannot be considered, like in the series cars case. However, to reach a satisfactory performance from the point of view of aerodynamics, it is good to take into account certain 3D constructive characteristics to obtain later results favourable in a CFD (Computational Fluid Dynamics) analysis. VR immersion is useful for a general analysis of the CAV's 3D shape and other important constructive elements such as ground clearance, the distance between wheels, etc. VR immersion is also useful when

analysing the prototype from an aesthetic and chromatic point of view. Different colour palettes can be used, analysing in detail the light reflection when different sources of artificial or natural light are used, simulated in VR much more realistically than in a 3D CAD work environment (figure 9).

Ergonomics - The analysis refers to how the assembly/disassembly of the engine components, the gas cylinder and the rest of the components that are part of the cabin components is performed. The driver can also conclude how favourable the access to the control components, pneumatic installation, steering wheel, brakes, etc. is. He also decides whether his position on the chair is optimal in relation to all the instruments and control levers inside (figure 10).



Figure 9. The details



Figure 10. A special driver's seat

Useful space analysis - Virtual immersion is almost unbeatable when arranging the components inside a system under analysis. Likewise, in the automotive industry and the case of the construction of automotive prototypes, the functional space must be carefully capitalised to respect specific rules and standards. Thus, the mock-up analysis of the interior can be much better retouched and optimised than visualising the 3D CAD model. In the case of prototypes specific to the PNEUMOBILE competition, special attention must be paid to the space intended for the gas cylinder. It must be able to be assembled/disassembled quickly, it must not influence the position/weight and stability of the CAV during travel and must not adversely affect the car structure's overall dimensions. Also, depending on the engine configuration and the pneumatic components' arrangement (especially the active ones, such as the pneumatic pistons) the VR immersion analysis of the functional space becomes useful.

Depending on the needs and interests of the prototype analysis in the Virtual Environment, various scenarios can be made from which one can extract the information necessary for improving the project and the prototype itself, which afterwards will have to be done physically [1]. In the automotive industry, there is no specific standard for creating these scenarios, each car manufacturer developing their own strategy for Virtual Prototyping (VP), defined graphically (CG - Computer Graphics) and mechanically (ME - Mechanical Engineering), Virtual environment (VE), and Digital Mock-Up (DMU). For example, one such strategy proposed by BMW in collaboration with the Fraunhofer Institute for Computer Graphics for the implementation of the DMU is [1]:

$$VP_{CG} \subset VP_{ME} \subset DMU.$$

6. Conclusion

In this article, we tried to present virtual immersion utilisation as a VRAD tool for a CAV prototype. This study can be extended to the prototyping stage for any industrial product. As far as we know, no participant in the PNEUMOBILE competition (now in its 14th edition) was asked to switch to series production for such a prototype. This does not mean that the future cannot offer a chance for this idea as well, especially since there are already enough attempts on the market to make CAVs in series. Starting from this thought, for the future, the *Upbair* team wants the prototyping through VRAD to be integrated naturally in the PDP and especially, to perfect this approach of rapid prototyping in the future.

By VR immersion, the goal is to get a perceptual approximation of a digital environment as close as possible to reality. The distances are misperceived, and we need an improvement in precise estimation. We briefly presented how VR immersion can be useful for making the virtual prototype so that the realisation of the physical prototype can then be as close as possible to the design team desideratum. We also presented a commonly used approach to transferring the 3D CAD model to VR through the Unreal Engine platform and Blueprints.

The design and analysis activity by virtual immersion was realised in the AVRENG laboratory (Augmented & Virtual Reality for ENGINEERING) from UPB where the doctoral and master students worked. The physical prototype was made at the Faculty of Robotics and Industrial Engineering. The steps that need to be followed to improve this rapid prototyping method are many and require students' involvement and dedication guided by teachers and collaborators from specialised companies. Collaboration with well-known partners in the automotive industry such as Institute Image - ENSAM (Chalon sur Saone, France) and Renault (factory in Romania) will help us develop this technology and prepare to transfer it to the automotive and other industries, considering that AR/VR/MR/XR are already Industry 4.0 technologies.

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