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RADICALLY INNOVATING THE AUTOMOTIVE DESIGN PROCESS WITH IMMERSIVE TECHNOLOGIES

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ABSTRACT
The automotive design process prevalent in industry that dictates transportation design education, is optimized to facilitate the frequent aesthetic renewal of personally owned vehicles for car-oriented cities. With its origins in the late 1920s, this hyper-specialized design process has barely changed from its original form. In this paper, we provide a brief account of the automotive design process from its origins (analog) to the present day (digital technologies), followed by a new paradigm instigated by immersive technologies. A passenger drone project is used as an example to describe the possibilities of immersive technologies in this radically innovated process. Enhancements from 2D and 3D to immersive and interactive 4D, enable a lean, yet contextualized process to design radically innovative vehicles.

Keywords: Automotive Design Process, Future Mobility, Immersive Technologies, Radical Innovation, Transportation Design Education

1 INTRODUCTION

In the late 1920s, General Motors (GM) decided to fight the dominant Ford Model T with style rather than pricing and technological innovation [1]. To create their next generations of cars, GM developed what we know today as the automotive design process[1]. Used by the design studio(s) of automakers, the automotive design process is a sequence of established operating procedures to create commercially successful vehicles that justify the resources required for their production [2]. This process has largely remained unchanged from its original form [3]. Indeed, automakers could afford to capitalize upon designing personally owned cars for a stable context, until recently that city infrastructures and mobility business models have started to change. This process is mainly similar in all automotive design studios while described somewhat differently by each. For the purpose of this paper, we subscribe to [3], but abstract their nine-phase model into a six-phase model where we introduce our own terms. These six phases are: 1) Technical package, 2) Ideation, 3) Development, 4) Refinement, 5) Final model or prototype, and 6) Approval.

Figure 1 provides an overview of the first four phases which we focus on in the remainder of this paper. In phase 1, the car's technical packaging is created based on the precisely dimensioned seating positions, layout of the driver and passengers, and the car's technical components. In phase 2, multiple design proposals are ideated using 2D freehand (and thus, dimensionless) sketches and renderings. In phase 3, a design shortlist is selected for development where the 2D dimensionless design proposals are translated into dimensioned 3D volumes using models. Once a direction from the shortlist is selected, in phase 4, final models are sculpted and iterated on until reaching a desired, precisely dimensioned outcome. In phase 5, these sculptures are used to create a final model or prototype that looks exactly like the real car. Phase 6 concludes the process with approval for production coming after feasibility is assessed.

[1] The term automotive design is also used in engineering focusing on the technical aspects of the vehicle (i.e. chassis, suspension, aerodynamics). In this paper we focus on the creative design aspect (i.e., aesthetics, usability). Specifically, we focus on the vehicle's exterior and interior which largely follow the same procedure.

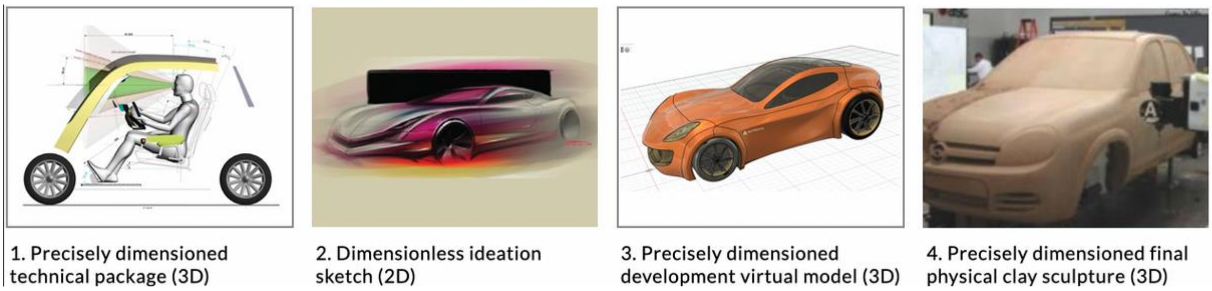

Figure 1. Snapshots of the first four phases of the current automotive design process (varied projects).

Described by [1], the original version of the automotive design process used analog paradigms of the 2nd industrial revolution and was mostly 2D in its first three phases: 2D technical drawings in the technical package phase; 2D sketches and renderings in the ideation phase, and 1:1 scale orthographic drawing in the development phase. It was only after these phases, in phase 4, that 3D physical models in full-size were produced using clay. Through the decades, the automotive design process was incrementally innovated through the integration of digital technologies until the contemporary version. CAD had the biggest impact by permitting the use of 3D virtual models in phases 1 (technical packaging), 3 (development), and 4 (refinement). However, the ideation or phase 2, remained based on freehand dimensionless 2D sketches. Moreover, despite being streamlined, the resource-intensive translation from 2D to 3D remained (Figure 1).

The most recent developments for this process are the emergence of immersive technologies. In recent years, these technologies are starting to radically advance the automotive design process into a new paradigm. Indeed, virtual reality (VR) and augmented reality (AR) provide the ability to design vehicles virtually at full scale using mid-air sketching. Additionally, video game engines (VGEs) facilitate adding interaction to immersive 3D models, effectively making them 4D [4]. The industry is already experimenting with immersive technologies, however in the present day, these technologies have not holistically and formally been integrated into the established automotive design process. As the automotive design studios possess a large and highly specialized workforce who are used to an established procedure and its related infrastructure, it becomes challenging for them to integrate immersive technologies throughout the entire process and at a large scale.

In this paper we present an automotive design process, developed free from industry constraints where 3D and 4D immersive technologies are integrated holistically. This process was generated at the University of Cincinnati Future Mobility Center, where the first and third author were previously affiliated. At this Future Mobility Center, 13 academic transportation design studio courses were co-developed and/or its output presented to the automotive industry and technology collaborators. The remainder of the paper is therefore structured as follows. In the next section (Section 2), we provide a brief account of the original automotive design process, its contemporary form, and the emerging paradigm using Schwab's industrial revolutions model [5]. We then describe our radically innovative automotive design process using a project from one of the 13 academic transportation design courses as an example – i.e., the design of a passenger drone (section 3). The paper ends with a discussion of how 3D and 4D immersive technologies enable a lean yet contextualized automotive design process appropriate for radically innovative vehicles of the future.

2 THE EVOLUTION OF THE AUTOMOTIVE DESIGN PROCESS

The brief evolutionary account of the automotive design process in this section forms a non-exhaustive basis for understanding our work. The summary provided here, is based on literature review reported in Section 2.1 and 2.2; Complementary observation of the latest developments in the field, and dialogue with the members of the automotive design community of practice, reported in Section 2.3. An overview of all research is provided in Figure 2.

2.1 The 2nd industrial revolution: from 2D to 3D through analog means

The original version of the automotive design process was created at the Art and Color Section of GM between 1927-1950 by Harley Earl [1]. With this process, GM introduced effective style changes for annual car models, utilizing a car archetype (engine, cabin, cargo, four wheels, etc.) that would cash in on a century of personal ownership business model and decades of established city infrastructure. Earl's process was mainly analog and 2D. The technical package was a 2D drawing based on an established car archetype prioritizing the driver (phase 1). Ideation was based on 2D freehand dimensionless paper sketches that dramatized the vehicle's proportions and showed design intent (phase 2). Since the ideation sketches were 2D, they had to be developed into 3D dimensioned form [6], going through a complex and resource-consuming translation [7]. The translation from 2D dimensionless to 3D dimensioned, required the creation of 1:1 full scale 2D drawings (phase 3). These drawings were then used as a template to create full-sized hand-made clay sculptures, iteratively refined towards a precise-dimensioned final vehicle model (phase 4). The same sculptures were used for the final model and prototype (phase 5), before being approved for (phase 6).

2.2 The 3rd industrial revolution: from 2D to 3D through digital technologies

Although the digital revolution started to impact the automotive design process in the 1960s [5], the automotive design process remained largely unchanged. The main reason for this stability was the personal ownership business model and related car-oriented city infrastructure. Therefore, the arrival of digital technologies only instigated an incremental change. In other words, digital technologies mainly tridimentionalized the process. Moreover, CAD advanced the technical package with 3D geometry (phase 1). Ideation remained 2D (phase 2), but now 3D models could be developed in CAD (phase 3), before creating final clay models (phase 4). As a result, the effort needed to translate 2D dimensionless sketches into 3D dimensioned form was reduced, but not eliminated. Since the translation from 2D to 3D is resource intensive [7], several attempts exist by scholars to tridimensionalize the ideation phase through digital technologies (phase 2). For example, [8] has proposed the projection-mapping of traditional 2D orthographic sketches into a CAD geometry used as an underlay for multiple viewpoints of the ideated design proposal which used to only provide one viewpoint as a paper sketch. [6] digitized tape drawing as an attempt to achieve more precise and editable 1:1 orthogonal drawing. [9] explored digital clay – sketching on 3D geometry, to ideate directly in 3D.

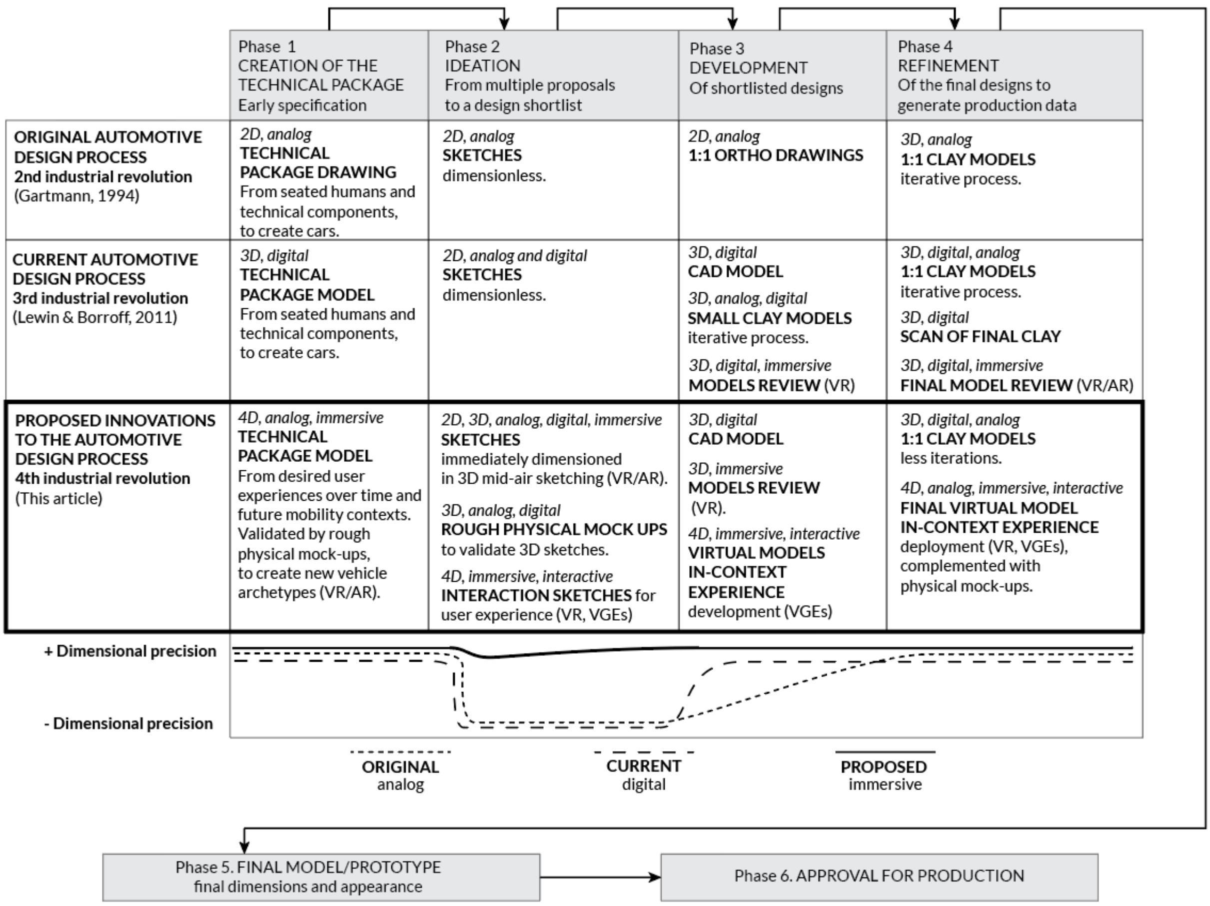

Figure 2. The three main paradigms of the automotive design process: analog or original (row 1) digital or current (row 2), and immersive or the radically innovated automotive process (row 3).

2.3 The 4th industrial revolution: the emergence of immersive technologies

Where before, the automotive design process largely remained unchanged, in the 4th industrial revolution the process is increasingly being disrupted. Significant change here is twofold. First and foremost, a new mobility paradigm is arising. The century-old personal ownership and car-oriented city infrastructure is transitioning into multimodal, autonomous, and shared mobility within sustainable cities [10]. Once specialized in developing cars, automakers need to rethink vehicle archetypes for their very survival [11]. This new scenery requires consideration of unestablished operations in sometimes not yet existing contexts. Returning to the automotive design process, we now must deal with new postures, layouts, and user experiences affecting the technical package to give an example. Second, the 4th industrial revolution comes with a series of "compounding effects of multiple exponential technologies" [12, p. 215]. The democratization of VR and AR for immersive 3D mid-air sketches, and the use of VGEs for 4D immersive and interactive in-context experiences present themselves as potential game changers in the automotive design practice. Early implementation of immersive technology in the established automotive design process is reported by [13] with the Powerwall – an electronic patio where one or more full-scale digital car models can be projected for surface evaluation, and CAVE – rooms with multiple projection surfaces that collectively display images that surround the viewer with the interior of a car, as examples (phase 4). More recent examples are the HYVE 3D – a not specifically automotive multi-user social co-design VR system for ideation (phase 2), developed by [14], and more democratized VR head-mounted displays developed among others by HTC and Oculus. As mentioned earlier however, to date, these technologies have not been holistically implemented in the automotive design process and at a large scale.

3 RADICALLY INNOVATING THE AUTOMOTIVE DESIGN PROCESS THROUGH IMMERSIVE TECHNOLOGIES IN ACADEMIA

3.1 Research context and rationale

In the field of automotive design, including the automotive design process, industry has always led education. The automotive design process is a highly optimized and hyper-specialized process which has become widespread in a community of practice [15] where design is viewed as craft rather than a discipline. Indeed, literature on the automotive design process, especially when it comes to education, is scarce which has resulted in a master-apprentice pedagogy. To ensure proficiency in this process, transportation design programmes work closely with and follow the workflows of automotive design practitioners in the industry. However, in the 4th industrial revolution, industry disrupted in such a way that it is finding its limits. It has then not been a surprise for us to experience a high interest of industry to collaborate and experiment with immersive technologies within an academic setting. The research reported in this paper is therefore a serious attempt to not only follow but inspire, even lead the industry. Free from the infrastructure and day-to-day constraints of automotive design studios, at the University of Cincinnati Future Mobility Center, a practice-led research approach was deployed [16]. Immersive technologies were explored in different phases of the automotive design process through 13 academic transportation design studio courses. All courses featured projects addressing future mobility challenges through vehicle concepts. Developed between 2016 and 2021, each project was executed in a semester. Among others we worked with GM, Fiat Chrysler Automobiles, Tata motors, Pininfarina, Jaguar Land Rover, Hankook Tire and Technology, Gravity Sketch, Autodesk, among others.

3.2 The radically innovated automotive design process: from 2D and immersive 3D to immersive and interactive 4D

The third row of Figure 2 provides an overview of the radically innovated automotive design process. The radically innovated automotive design process maintains the same general phases as the prior two processes (the original and the contemporary). The difference is the integration of immersive technologies. In phase 1, instead of creating a 3D model behind a computer screen and departing from static seated figures to design a car, we propose the creation of the technical package in VR and at 1:1 scale. Moreover, the technical package is created considering new and non-existing mobility contexts in which the resulting occupant position and that of the technical components of the vehicle are driven by experience flows (4D), resulting in disruptive innovation (e.g., new vehicle archetypes beyond the car) [17]. In phase 2, ideation is advanced from 2D to 3D by using immersive sketching while validating the virtual model's dimensions with rough physical mock-ups. Expanding ideation from 2D to 3D using

VR and/or AR, augments the dimensional precision in comparison to prior versions of the automotive design process (Figure 2). In addition to the ideation of the physical vehicle, 4D immersive interactive sketches using VGEs are proposed to design the vehicle's desired use experience (e.g., operating a vehicle with unconventional controls). In phase 3, for the development of shortlisted design, we propose the substitution of small clay models with VR reviews which saves resources. At this phase, the assets necessary to create a 4D immersive and interactive virtual model experienceable in-context are developed (i.e., coding the vehicle interactions, creating a virtual city context where the vehicle situates). In phase 4, the refinement of final designs is still done with full scale clay models. However, the number of iterations is now reduced, and more resources are saved, since a part of the refinement is taken care of in VR-reviewed CAD during the previous phase. At the end of this phase the final version of the 4D immersive and interactive experience is deployed (i.e., a trip through a city). Finally, the 4D immersive and interactive experience can inform about further refinements before investing time and resources to create the final model and prototype (phase 5) before approval for production (phase 6).

3.3 Describing the radically innovated automotive design process through a project example: the passenger drone project

We now describe the holistic integration and benefits of immersive technologies for the automotive design process using a project from one of the automotive design studio courses: the design of a passenger drone. This is a new type of vehicle to move a person in the city from roof to roof with a maximum 30-minute flight range. In a project with a collaborative component, two students were briefed to approach a passenger drone design from different angles: the design of the physical drone, and how to fly it. Figure 3 shows the student work samples of this project. Both students began by using rough physical mock-ups to create a vehicle package that provided a comfortable, yet adventurous, "superhero" flight user experience (phase 1). The design of the physical vehicle used both 2D ideation sketches and immersive 3D mid-air sketching in VR (phase 2). Having 3D geometry as output from the ideation phase accelerated the creation of the final dimensioned CAD (phase 3 and 4). On the other side of the project, the design of how to fly the drone was created by using a rough physical model, an HTC Vive tracker, and the Unity video game engine to design, test, and refine the flight experience and the type of controls required (phase 2). A 4D immersive contextual model was developed to simulate the drone operation experience. To achieve this experience, a virtual city was modelled, the vehicle virtual model was inserted in the scene and coded, and the rough physical mock-up was used to simulate the passenger posture (phase 3). The experience was deployed (phase 4) and the project critics were able to sit on the physical buck and fly the vehicle versus seeing the project on a poster or behind a screen.

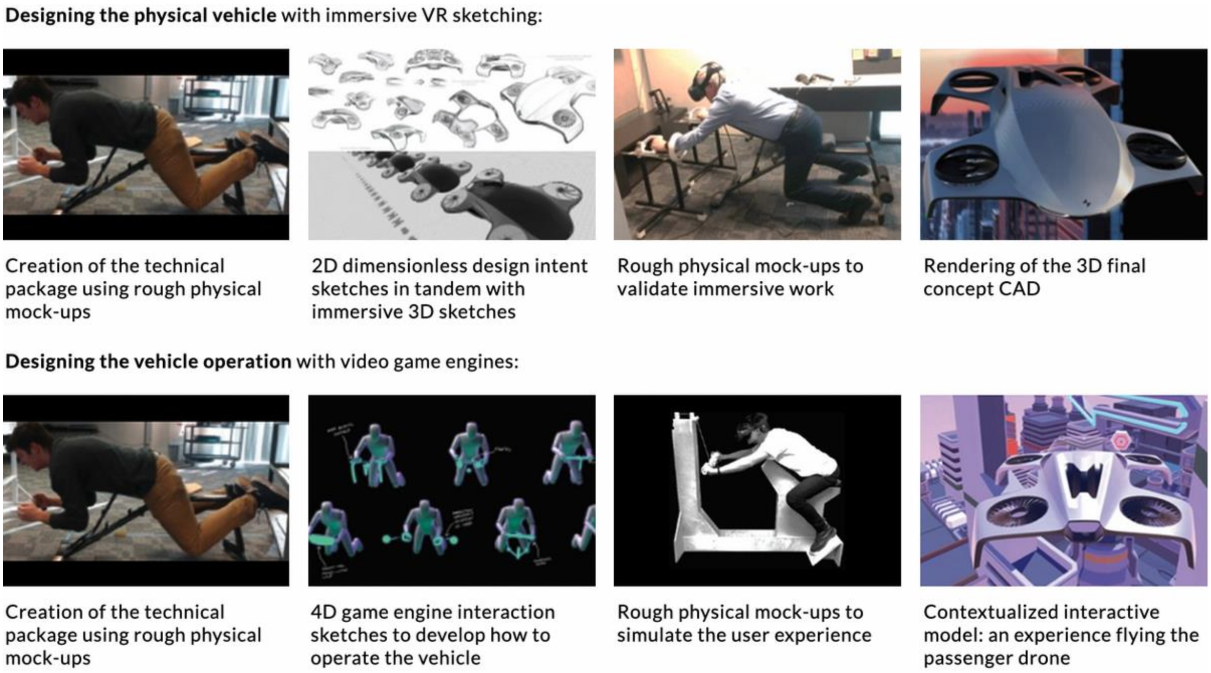

Figure 3. The automotive design process applied in a passenger drone project.

4 DISCUSSION AND FINAL WORDS

We applied immersive technologies to 13 transportation design courses at the University of Cincinnati Future Mobility Center between 2016 and 2021. In a constant state of dialogue, the courses were co-developed and/or their output was presented to the automotive design community of practice and technology collaborators. The accumulated insights allowed us to propose a radically innovated automotive design process where immersive technologies are holistically integrated.

Our work has three main contributions: 1) We provided a brief account of the original automotive design process (analog, mainly 2D), followed by the incrementally innovated contemporary process (digital, mainly 3D), and finally the emerging new paradigm (immersive and interactive 4D); 2) We proposed a radically innovated lean automotive design process by tridimensionalizing the ideation phase and holistically upgrading all four phases through the integration of 4D.immersive and interactive technologies. Our process allows for the creation of radically innovative vehicles beyond the car and for new or not yet existing mobility contexts; 3) Finally, we presented a project example featuring the physical and interactive design of a passenger drone as a design precedent.

Using university-level courses to (radically) innovate the automotive design process for industry use also comes with some limitations. Academic projects are usually a semester long (15 weeks), executed by one student or a small student team, and run with small budgets. Creating physical full-scale models is then not feasible. Nevertheless, academic student projects benefit from a freedom not available in industry while interesting enough to feed it.

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