ENVIRONMENTAL DESIGN

4th International Conference on Environmental Design

9-11 May 2024

A cura di
Mario Bisson

MDA
MEDITERRANEAN DESIGN ASSOCIATION

ENVIRONMENTAL DESIGN

Conference proceedings of the
4th International Conference on Environmental Design

Environmental Design : IVth International Conference on Environmental Design
A cura di Mario Bisson

Proceedings (reviewed papers) of the IVh International Conference on Environmental Design,
Mediterranean Design Association | www.mda.center | info@mda.center
9-11 May 2024, Ginosa, Italy

Progetto grafico ed impaginazione: Federico De Luca e Giulia Alvarez
Immagine di copertina: Federico De Luca
ISBN 978-88-5509-634-8

Palermo University Press | Finito di stampare nel mese di Maggio 2024

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INTRODUCTION

11 Environmental Design
Mario Bisson
Politecnico di Milano, Italy

SUSTAINABLE DEVELOPMENT

15 RAISE ecosystem: urban design for accessible and inclusive Smart Cities
Francesco Burlando[1], Federica Maria Lorusso[2], Claudia Porfirione[1]
[1]University of Genoa, Italy
[2]University of Campania Luigi Vanvitelli, Italy

27 Culture, meaning, value and sustainability: A terminological analysis
Piera Losciale
Politecnico di Bari, Italy

37 Bio-inspired design: A systemic and interdisciplinary design approach to increase the sustainability of processes and products
Lucia Pietroni, Mariangela Francesca Balsamo, Giuliana Flavia Cangelosi
University of Camerino, Italy

49 Eco-sea design. Transdisciplinary products and services for sustainability in seaside contexts
Ivo Caruso[1], Vincenzo Cristallo[2]
[1]Università degli Studi di Napoli Federico II, Italy
[2]Politecnico di Bari, Italy

63 Fashioning a Sustainable Future: Navigating Zero-Waste Practices in Textile Chain
Maria Antonia Salomè
Università degli Studi di Firenze, Italy

75 The black hole of the fashion system: The contribution of design to the sustainable transition of the fashion system
Elena Pucci
Università degli Studi di Firenze, Italy

87 Digital art direction and sustainable communication for fashion in Italy: A literature review
Filippo Maria Disperati[1], Elisabetta Cianfanelli[2]
[1]Università degli Studi della Campania "Luigi Vanvitelli", Italy
[2]Università degli Studi di Firenze, Italy

97 Fast Fashion. Sustainability and the negative psychological and social impacts for consumers
Giovanni Maria Conti
Politecnico di Milano, Italy

105 Mixed reality for addressing boredom at work: grounds and perspectives for PhD
Francesco Musolino, Michele Fiorentino
Politecnico di Bari, Italy

113 Design as a Catalyst for Sustainability Bridging Disciplines in the Anthropocene
Dario Russo
Università degli Studi di Palermo, Italy

125 Evolving practices in sustainable communication design: An integrated approach
Francesca Scalisi, Dario Russo
Università degli Studi di Palermo, Italy

SOCIAL INNOVATION

141 Urban lifestyle in twenty years.
Forecasts from a Young Generation of Interior Designers
Luca Guerrini
Politecnico di Milano, Italy

159 Design as a catalyst for rural regeneration:
Insights from a Research through Design study
Alessandro Ianniello[1], Riccardo Palomba[2]
[1]TU Delft, The Netherlands
[2]IUAV, Italy

175 The role of the communication design for the Mediterranean enhancement and development. The representative case studies map
Chiara Tuttolani
Politecnico di Bari, Italy

179 From concepts to open products:
The experience of a design hackathon for inclusive open-souse products
Federica Caruso, Venanzio Arquilla
Politecnico di Milano, Italy

191 ReMade Community Lab, Design explorations in a Proximity System
Susanna Parlato
Università degli Studi di Napoli Federico II, Italy

203 Utensilia© to design. On the "process by which people go about producing things"
Rossana Carullo
Politecnico di Bari, Italy

215 Color loci placemaking: Color and processes of place appropriation
Cristina Boeri
Politecnico di Milano, Italy

225 Editorial Design and the Influence of Racism on Black Representation in Brazilian Magazines and Newspapers: The Panorama Before and after George Floyd and João Alberto Silveira Freitas
Gustavo Orlando Fudaba Curcio, João Vitor Pereira Moura
Universidade de São Paulo, Brasil

241 Playing as a cultural dissemination strategy. Eco-bab:
Designing collaborative, playful and educational experiences
Nicolò Ceccarelli, Nađa Beretić
University of Sassari, Italy

253 Functionality and significance in the design of tourist and community interaction structures in the Colta Lagoon
Sandra Núñez[1], Claudia Balseca[1] and Eliska Fuentes[2]
[1]Universidad Indoamérica, Ecuador
[2]Universidad Técnica de Ambato, Ecuador

261 A Journey into Social Innovation through the Tombolo of Mirabella Imbaccari From History to Project Perspectives and the First Workshop of the Community Foundation of Messina via the Tombolo Academy
Luca Fois, Camilla Guerci
Politecnico di Milano, Italy

273 Urban interiors. The domestic space and the city/the street as a living room
Tiziano Agieri Rinella
IUAV, Italy

TECHNOLOGY APPLICATIONS

293 The 'New Morphologies':
When Technology Becomes Gender-Neutral
Matteo O. Ingaramo, Martina Labarta
Politecnico di Milano, Italy

305 UX Design in The Context of Navigation Aid Equipment Maintenance.
A new approach to Monitoring and Control System Design
Elie Barakat[1], Venanzio Arquilla[2], Maximilian James Arpaio[1]
[1]Thales Italia Spa, Italy
[2]Politecnico di Milano, Italy

317 Enhancing User Experience in Autonomous Driving Levels 4 and Above:
A Novel Seat Concept for Motion Sickness Mitigation.
Venanzio Arquilla, Shangyi Bai
Politecnico di Milano, Italy

333 Digital Manufacturing of Tactile Maps to Improve Accessibility at Archaeological Sites
Alfonso Morone, Edoardo Amoroso
Università degli Studi di Napoli Federico II, Italy

347 TREELOGY: Preserving Urban Forests through IoT Monitoring Data of Greenery
Alfonso Morone, Mariarita Gagliardi, Silvana Donatiello
Università degli Studi di Napoli Federico II, Italy

361 Research into the exterior walls of residential buildings in the context of
sustainable construction based on bio-based materials and waste
Alberto Reaes Pinto, Marlene Canudo Urbano, Carlos Oliveira Augusto
CITAD / Universidade Lusíada, Portugal

377 Design, cultural heritage and technologies:
New forms of dialogue between the user and museum spaces.
Giusi Castaldo, Mario Buono, Elena Laudante
Università degli Studi della Campania "Luigi Vanvitelli", Italy

389 Environmental Impact of Wood, Steel, and Concrete in Residential Buildings
Sonsoles Vela, Ruben Garcia Rubio
Tulane University, USA

409 A sustainable territorial development
Luca Bullaro
Universidad Nacional de Colombia, Colombia

HEALTHCARE AND WELLNESS

419 Textures design for Augmentative and Alternative Communication (AAC)
for people with deaf- blindness and multi-sensory impairment
Denise Dantas[1], Lia Sossini[1], Barbara Del Curto[2]
[1]Universidade de São Paulo, Brazil
[2]Politecnico di Milano, Italy

431 Design against cancer. Topics and projects for a new culture of prevention.
Erminia Attaianese, Ivo Caruso, Carla Langella
Università degli Studi di Napoli Federico II, Italy

443 Thriving children's perceptual learning through educational environments
color and material design
Elisa Longoni[1], Michele Zini[2], Barbara Camocini[1]
[1]Politecnico di Milano, Italy
[2]ZPZ Partners, Italy

455 Enhancing Healthcare Systems: Redefining Strategies and Stakeholder Engagement for Community Care Service Evolution
Federico De Luca, Daniela Sangiorgi
Politecnico di Milano, Italy

POLICY AND GOVERNANCE

467 The Project of ethical visions for new enterprises in the South
Rosa Pagliarulo
Politecnico di Bari, Italy

475 REMANUFACTURING ITALY. The role of design in the manufacturing chains of the southern contexts, for the development of territorial cultural heritage, between local archetypes and global connections.
Domenico Colabella
Politecnico di Bari, Italy

479 Re-Made in … Locally. The empowerment of regional practice
Lisa Hockemeyer[1,2], Anna Santi[2]
[1]Kingston University, UK
[2]Politecnico di Milano, Italy

493 Green design for resilient urban pathways
Davide Bruno[1], Felice D'Alessandro[2]
[1]Politecnico di Milano, Italy
[2]Università degli Studi di Milano, Italy

ALTERNATIVE FUTURES

507 Design and Literature for Education: Academic and Pedagogical Transdisciplinary Integrated Lab as Innovative Project for Graduate Programmes
Michaella Pivetti[1], Diana Navas[2]
[1]Universidade de São Paulo (USP), Brasil
[2]Pontifícia Universidade Católica de São Paulo (PUC-SP), Brasil

521 What if interactive artifacts would disrupt human relations?
Andrea Di Salvo
Politecnico di Torino, Italy

533 The (Un)Sustainable Future - Design and Resignification of Materials and Processes
Maria João Barbosa, Benedita Camacho, Diogo Frias Riobom, Bernardino Gomes
CITAD / Universidade Lusíada, Portugal

549 Shaping the future of automotive design: The automotive experience design lab
Venanzio Arquilla, Giorgia Ballabio
Politecnico di Milano, Italy

561 Defining garment quality for user experience design in metaverse: The outerwear case study
Dario Gentile, Michele Fiorentino
Politecnico di Bari, Italy

571 Research through Design in Multisensory Narrative Dimensions
Clice de Toledo Sanjar Mazzilli
University of São Paulo, Brazil

585 Anthropogenic Narratives. Imagination and Anti-Disciplinarity for the Communication of Non-Human Perspectives
Francesco E. Guida[1], Martina Esposito[1], Enrico Isidori[2]
[1]Politecnico di Milano, Italy
[2]Università degli Studi di Napoli Federico II, Italy

Shaping the future of automotive design: the automotive experience design lab

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Keywords:
UX Design
Automotive UX HMI,
Interaction Design
User Research

Abstract

As technology continues to reshape the automotive landscape, a radical transformation is underway in the design of automobiles. The focus is shifting from the vehicle itself to the onboard experience, marking a pivotal moment where driving becomes less central, and the «passenger» experience takes center stage. The proliferation of multimedia entertainment systems, ambient lighting, interactive sounds, and other non-driving elements reflects this shift, especially in anticipation of the impending era of autonomous driving.

This paper presents a thoughtful exploration of this evolving paradigm, culminating in the establishment of the Automotive eXperience Design Lab (AXD): a dedicated space and simulator for testing new interactive systems both in physical and digital dimensions. Leveraging the lab's expertise, prototypes can be efficiently developed and tested, providing valuable insights into the complex and multidimensional nature of the onboard experience.

The Automotive eXperience Design Lab represents an initiative offering new tools and operational methods tailored for emerging professional roles in the realm of automotive design.

Introduction

Industry Requirements

The automotive sector represents a constantly developing scenario. The impetus given by the growth of emerging markets, the acceleration in the implementation of new technologies, the establishment of policies related to sustainability, and changes in consumer preferences, as well as digitization and the consolidation of new business models, are forces that have long been driving the growth of technology-driven trends in the automotive world (McKinsey&Co, 2016). A clear showcase of this technological push was CES held in Las Vegas in January 2024 (Consumer Electronics Show). One of the prevailing themes concerns the integration of AI (Artificial Intelligence) within in-vehicle systems. Volkswagen collaborating with Cerence presented the integration in the software of Chat GPT to answer general knowledge questions. The company guarantees that there will be no access to vehicle data and that requests will remain anonymous (Lekach, 2024). Mercedes-Benz refers to the MBUX Virtual assistant as dialoguepartner. The system has four personal traits: natural, predictive, empathetic and personal (Group, 2024). The CES 2024 underscored the centrality of the digital experience as a pivotal differentiation between brands. Many industry makers are creating immersive experiences close to gaming; an illustrative example is Afeela arising from a Sony-Honda joint venture, which integrates the function of streaming games from PlayStation 5 (Audoin, 2024). This phenomenon has already been investigated and it continues to embrace technological innovations. In 2023 Holoride garnered recognition from CES as an innovative product in the field of entertainment. Holoride's technology makes it possible to synchronize digital content through a VR headset with movement, and the position of the vehicle in real-time. Creating experiences close to gaming will become more and more established through the spread of electric vehicles, as a time for example to manage breaks for recharging, but also through the incremental spread of self-driving vehicles.

These technological megatrends correspond to industry requirements for the near future and are profoundly changing the mobility ecosystem, including user experience perspective. The conceptual framework known as CASE (Connected, Autonomous, Shared & Services, and Electrified), initially introduced at the Paris Motor Show in 2016, has been fundamental in steering the trajectory of industry development to follow. These trends are also particularly relevant because they align with the needs dictated by the environment surrounding the automotive world. Such as the need to implement regulations to fight climate change; the need to increase road safety by reducing accidents through automation; and the need to embrace changes in consumer values and behaviours that encourage the transition from ownership to shared service use (What Is "CASE"?, 2022). The implementation of these innovations is ensured by the increasingly massive integration of hardware and software, great computational power, and the introduction of increasingly advanced technologies, such as artificial intelligence (Fedele, 2023; John, 2023). The value of the software component in enabling these innovations is fundamental and greater than the mechanical hardware (Deloitte, 2020). This is why automakers focus on software optimization rather than hardware creation. For the same reason, collaborations with technology players often arise to offer compelling digital services. A classic example is the mirroring of the personal devices in the infotainment system that enables the use of mobile applications, which are often preferred over native apps.

The vehicle is no longer merely a marvel of mechanical engineering but is increasingly approaching a consumer electronic device. The closeness between these two worlds found visibility during CES in Las Vegas, a moment dedicated to consumer electronics products where automotive occupies more and more space (Audoin, 2024). This transition affects the way users, drivers, and passengers, experience the vehicle, bringing the user experience to the center of the design (Accenture, 2021).

Consumer Mobility Life Area

The boost the industry is getting comes not only from technological innovations but also from the needs and changes in consumer behavior and preferences. The ecosystem strategy map defines ten areas intended to holistically represent human life, including mobility (Ecosystemizer, 2020). All areas are deeply interconnected (Pwc, 2023). Hence, the requirements for the automotive industry are not only determined by the area of mobility, which mainly indicates needs in transportation but also by health, recreation, work, spirituality, consumption, socialization, education, entertainment, and living. Users' needs as well as consumption patterns and lifestyles are constantly evolving and follow generational changes. Younger generations, for example, attach new values to the concept of mobility: the travel experience must be fun; it must offer the possibility of performing other activities while moving; there is a growing demand for safety; sociability must be fostered by design, for example, by sharing the route; there must be attention to reducing the environmental impact of transportation; and it is important to ensure the security of data generated during travel and personal data shared with the vehicle (Viviani & Panzeri, 2021).

In this constantly developing scenario, user experience is the game-changer for most of the challenges in the automotive field. User Experience in Automotive

User experience is described as ''a person's perceptions and responses that result from the use or anticipated use of a product, system, or service'' (ISO 9241-210:2010(En), Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems, n.d.). It is mostly affected by three factors: user status, system characteristics, and interaction context (Ebel et al., 2021). The context in which vehicle interactions occur is a dual-task environment. This means that the user must handle two tasks simultaneously: they may also undertake secondary actions, while engaged in the primary activity of driving. Before autonomous driving takes over, one of the biggest challenges in designing user experience within the vehicle, concerns refining iterations with infotainment systems (IVIS) while keeping safety as the primary objective. The number of functionalities made available to the driver for controlling the vehicle is constantly increasing. Instead of having a separate controller for each function, multifunctional systems are employed to handle this complexity. It would be impossible to imagine a dashboard with one controller dedicated to each functionality. The introduction of touchscreens reflects this trend. The digital display allows navigation within very complex and branching streams, following interaction patterns that users are already accustomed to using with personal devices. Users increasingly expect to find these kinds of interactions in the vehicle, and if the built-in operating systems are not intuitive enough, third-party services such as Apple Car Play or Android Auto are used. Designing the interaction with these systems is particularly challenging because, despite a large amount of accessible features, design aims to minimize user interaction, directing visual attention toward the road. Interactions with touchscreens, which is the preference and nearly the design standard, inexorably results in shifting visual attention to the screen to locate buttons and elements in the interface (Richter et al., 2010). This occurs because this interaction model relies much more on the visual rather than the tactile feedback. The focus on safety issues brought about by the dual-task environment not only affects the experience of the driver but also that of all other passengers. Nevertheless, the entertainment activities made possible inside the vehicle seem to know no bounds, and, with the advent of autonomous driving, will increasingly involve the driver as well. In fact, with this shift, the vehicle will become more and more intelligent and responsible for the driving activity, turning the driver first into a rider and then into a passenger. This transition allows new models of interaction to be imagined and designed.

Some critical aspects of this race towards digitisation and the increasingly invasive introduction of advanced technologies such as AI must be considered.

For example, the constant increase in functionalities, made possible by technological development and in particular the power of integrated software in the vehicle, could lead to the phenomenon called 'feature creep'. That is the accumulation of features in even greater numbers than users actually demand. This could make the experience more complex than it needs to be. It is the result of a design that does not take users' needs into account but looks more to technology as a silver bullet.

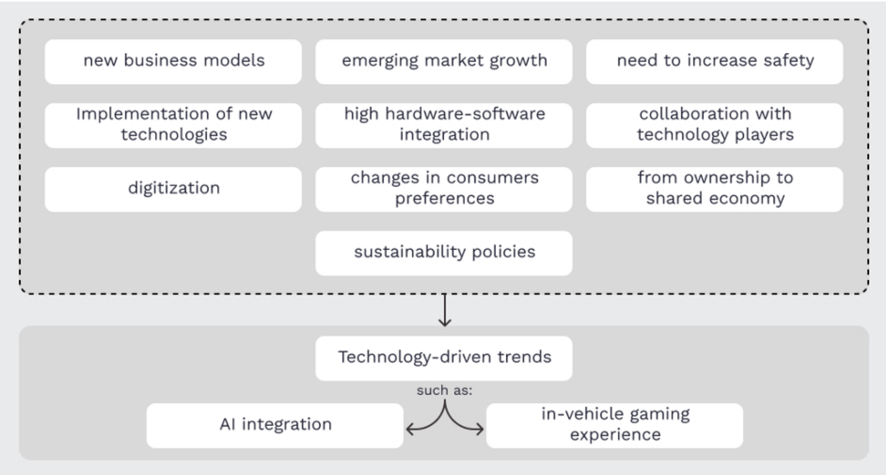


Figure 1. Factors facilitating technology-driven trends

Similarly, these trends appeal to users who are familiar with certain interaction patterns and digital interfaces. The risk is to move towards an increasingly less inclusive design. For example, the use of digital interfaces, especially touchscreen, does not fully consider the needs of those with reduced visibility. This condition often affects older people which, in more developed countries, also coincides with the majority of the population (Bradley et al., 2016; Young et al., 2017). A way to limit this condition could be for example using a multi-channel approach, not just relying on visual feedback. It is important to design with an inclusivity methodology, considering permanent, temporal, and situational disabilities.

Many of the trends highlighted previously will become increasingly popular as the introduction of autonomous vehicles takes hold. However, this scenario does not hide concerns and challenges to be overcome. Experts in this area mainly focus on the following points (What Self-Driving Cars Tell Us About AI Risks - IEEE Spectrum, n.d.). The issue of safety: malfunctions or errors in artificial intelligence systems can endanger the lives of drivers, passengers and pedestrians. The ethical issues involved in AI decision-making, such as in situations of choice between life and death. The issue of cybersecurity: vehicle connectivity increases exposure to possible cyberattacks. Finally, the issue of privacy of user data, since the vehicle is able to produce and collect a lot of information on preferences and behaviour.

Literature Review

To govern the complexity of user experience study, research centers often rely on simulation platforms as tools for prototyping and user testing. These platforms also facilitate the examination of the interaction between physical and digital elements in the user experience within the vehicle, thereby fostering a comprehensive understanding of user interactions and paving the way for the development of more intuitive, user-centric interfaces.

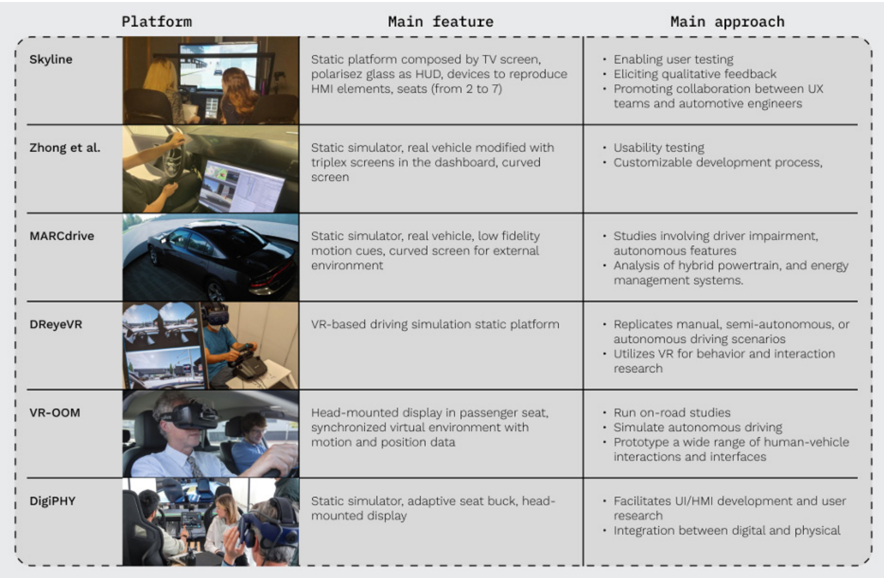
This section aims to describe the state-of-the-art driving simulators used mostly in laboratory settings to develop and study on-board user experience and in particular HMI. The literature around driving simulators is extensive and encompasses different kinds of platforms and associated research. Different classification models have been proposed: some researchers distinguish driving simulators according to their intended application, such as research or training (Blana, 1996), while others classify them according to fidelity level (Seropian et al., 2004). Eryilmaz and other researchers propose a four-level classification scheme taking into account: general features, motion system, visual system, and sound system (Eryilmaz et al., 2014). Following this frame, this section focuses on platforms utilized primarily for research purposes, with a medium-high level of fidelity, without motion systems, and that boast relatively sophisticated visual and auditory capabilities. Fixed-base driving simulators are the most common structures applied in research centers. The main reasons for that are cost, ease of implementation, as well as greater flexibility (Bruck et al., 2021).

Skyline is an example of a rapid prototyping driving simulator platform, used in Intel Labs to enable iterative development of in-vehicle user interfaces through user testing (Alvarez et al., 2015; Alvarez & Rumbel, 2017). Researchers highlight the efficiency of the platform in devising research hypotheses and rapidly prototyping solutions in realistic driving environments. Skyline is mainly used to elicit qualitative feedback through user testing. In addition, the authors highlight the importance of such a platform in creating an environment of contamination between the UX team and automotive engineers.

Zhong and others in their research create a driving platform to test HMI in autonomous driving, confirming the efficiency of using driving simulators for usability testing (Zhong et al., 2022). The authors point out how customized development of driving simulators is time-consuming, highlighting the need for a more efficient process, adopting for example modularity. The simulator used in the research is composed of an existing vehicle, modified through the addition of a triplex screen in the dashboard part, and other small body components to achieve full acquisition and input of driver control signals. A similar platform used for research purposes is the MARCdrive, installed in the McMaster Automotive Resource Centre (MARC). The laboratory setting involves a real vehicle facing a curved screen with 210 degrees of field of view (Bruck et al., 2021).

Numerous studies rely on VR devices to replicate simulation environments. DReyeVR is a VR-based driving simulation platform built to facilitate research in the fields of behavior and interaction in manual, semi-autonomous, or autonomous driving situations (Silvera et al., 2022). VR-OOM system involves the use of a head-mounted display while the user is in the passenger seat. The virtual environment is synchronized with motion and position data from outside. VR-OOM supports testing exploratory design concepts graphical user interfaces, sound interfaces and motion interfaces for autonomous vehicles (Goedicke et al., 2021). In these examples, the balance between the physical and digital world is entirely shifted to the digital, and virtual aspects, reducing the focus on the physical part. In contrast, XRoom represents an example in which physical and digital worlds meet in a more balanced way; it is a mixed-reality simulator that allows virtual elements to be superimposed on unmodified vehicles (Goedicke et al., 2021).

A case outside academia is DigiPHY, a solution, proposed by GranStudio, composed of an adaptive seat buck and an open design platform. DigiPHY highly integrates the virtual and physical worlds by creating immersive experiences. User research and development of UI and HMI are among the fields of application. The platform allows to set different devices as screens to study the interactions. GranStudio highlights the multidisciplinary of the platform, which enables collaboration between designers and engineers (https://www.granstudio.com/digiphy).



Platform		Main feature	Main approach
Skyline		Static platform composed by TV screen, polarisez glass as HUD, devices to reproduce HMI elements, seats (from 2 to 7)	• Enabling user testing • Eliciting qualitative feedback • Promoting collaboration between UX teams and automotive engineers
Zhong et al.		Static simulator, real vehicle modified with triplex screens in the dashboard, curved screen	• Usability testing • Customizable development process,
MARCdrive		Static simulator, real vehicle, low fidelity motion cues, curved screen for external environment	• Studies involving driver impairment, autonomous features • Analysis of hybrid powertrain, and energy management systems.
DReyeVR		VR-based driving simulation static platform	• Replicates manual, semi-autonomous, or autonomous driving scenarios • Utilizes VR for behavior and interaction research
VR-OOM		Head-mounted display in passenger seat, synchronized virtual environment with motion and position data	• Run on-road studies • Simulate autonomous driving • Prototype a wide range of human-vehicle interactions and interfaces
DigiPHY		Static simulator, adaptive seat buck, head-mounted display	• Facilitates UI/HMI development and user research • Integration between digital and physical

Figure 2. Driving simulator platform from AXD Lab

One area in which driving simulators are employed concerns user testing; the ability to integrate biometric data collection tools into research makes this method particularly effective for safety studies. For example, Liu and others recently recorded the EEG (electroencephalogram) signal during a test to assess differences in the workload of three different interfaces (Liu et al., 2023). Other biometrical data deeply investigated in a research study is visual attention. In their study Calvi, D'Amico and Vennarucci validate the eye-tracker system as very effective systems for evaluating driver's behaviors in simulated scenarios, demonstrating that the driver's response in real and simulated driving is the same in terms of fixation distance and duration (Calvi et al., 2023). In their study, they relied on a fixed-base driving simulator. Soares and others conducted a review of 23 studies on driving simulators developed for drowsiness and fatigue analysis (Soares et al., 2020), showing a great interest in this research field. All 23 studies considered biological data collected through technological devices. Among the biometric data that can be investigated is electrodermal activity (EDA). Khai and others analyze electrodermal activity to investigate stress and anger as primary emotions leading to possible accidents involving the driver (Khai Ooi et al., 2016).

The approach undertaken in the AXD lab underscores the importance of achieving a balanced integration between the physical and digital worlds. Considerable effort is directed toward prototyping the physical components of the simulation setting. However, within a research context like that advocated by the AXD lab, it is crucial to recognize that certain aspects of the user experience, particularly those encompassing sensory elements, may not receive adequate attention (Losada et al., 2020). This enables a focus on digital interactions without ever forgetting that they take place in a physical context, which affects their quality and perception by the user.

In addition, as the literature suggests, approaching the challenges with a multidisciplinary approach could be successful. Involving in the process at the same time design and engineering disciplines offers a more profound understanding of user experience dynamics (Kessels, 2023). Within the AXD lab, the synergy derived from the collaboration among different disciplines constituting the laboratory enables the integration between these digital and physical components. This facilitates a more holistic view of the issues and further research in various fields.

This paper aims to detail the approach underlying the operation of the AXD, positioning it as an example of research development in the context of in-vehicle user experience in the automotive realm. The composition of the laboratory encompassing human resources and technological assets will be described. The paper especially wants to emphasize the value given by the multidisciplinary work done and the integration of digital and physical experience.

AXD (Automotive eXperience Design)

Lab composition

The laboratory originated within the Politecnico di Milano, proposing itself as a space where to study the user experience in the interaction with the vehicle and specifically within it, building experiences that embrace both the physical and digital worlds. The activities undertaken within the lab are developed in all phases of design: from scientific and market research to the design phase of new interactions, passing through prototyping, according to various levels of fidelity, and concluding with the user testing and data analysis phase.

The core of the lab transcends the aggregation of its physical (platform) and non-physical (software) assets; rather, it is defined by the contamination of skills and synergy derived from different disciplines, such as the world of design, mechanical engineering, and management engineering. Especially these three poles are involved due to previous experiences and validated expertise such as the eXperience Design Academy (XDA - https://xdapolidesign.com/en/). The XDA has expertise in in-vehicle user experience research and design, honed through projects such as Base5G and collaboration with the Master's in Transportation & Automobile Design (TAD) (https://www.polidesign.net/en/formazione/interior-design-and-architecture/master--transportation-automobile-design/).

The iDrive Lab (https://www.idrive.polimi.it/) affiliated with the Department of Mechanical Engineering, is co-involved in the study of behavioral aspects between vehicle, driver, infrastructure, and surroundings. especially the lab specializes in augmented, virtual, and mixed reality prototyping. The expertise of the lab often meets that of the design side, as evidenced by the collaboration with XDA on the 5G base project (https://www.base5g.polimi.it/).

Furthermore, the discipline of management engineering contributes to AXD lab the knowledge and expertise developed within the PHEEL lab (PHysiology, Emotions and Experience Laboratory https://www.polimi.it/ricerca/la-ricerca-al-politecnico/laboratori/laboratori-interdipartimentali/pheel-physiology-emotion-and-experience-laboratory), specializing in the analysis of an individual's biological and physiological signals and expert evaluation to study the behaviors of individuals in response to specific stimuli.

The competencies derived from these three poles intermingle at every stage of the process, allowing for a holistic view of the challenges, gathering different perspectives, and creating new avenues for learning and research.

For the figure of the designer, multidisciplinary is crucial particularly during iterative phases of design and prototyping. Collaboration with mechanical engineering experts enables designers to conceptualize having the integration of hardware and software in mind, approaching technology to imagine a more complete interaction. In the prototyping phase, designers and engineers collaborate to develop HMI prototypes. A prevalent approach within the lab involves using prototyping systems that allow for the integration of hardware and software. Notably, platforms such as Protopie Connect exemplify this integration (https://www.protopie.io/blog/tag/protopie-connect), allowing to control Arduino (https://www.arduino.cc/) through commands designed with Protopie Studio, enabling seamless communication between digital and physical worlds.

During the evaluation phase, the collaboration is particularly promising since expertise from both the design world for experience evaluation and the knowledge of management engineers in biometric evaluation methods appear to be critical. Researchers within the AXD lab have various tools for the testing phase to collect biometrical data, in particular eye movements, brain activity and electrodermal activation.

The next section will describe the platform components and the tool used for research purposes.

Platform Components

The driving simulator of the AXD lab is a flexible platform, which can respond to different needs. The objective of the platform is to recreate the user experience inside the vehicle so that design hypotheses can be tested directly with users.

For the conditions to be as close to reality as possible, the laboratory seeks a high-fidelity level, which is why the platform has been designed and created to be flexible and its configuration can be modified according to specific requirements. This level of fidelity is reached through integration between hardware and software.

The physical components include:

- Structure of the platform
- External instrumentation to recreate the simulation environment
- Data collection equipment
- Hardware required for data processing

The simulator is built over a height-adjustable platform, that allows the replicability of different car configurations: it is possible to change the trim from a sedan to an SUV. The structure features four doors with armrests and storage compartments and a panoramic roof. The interior is equipped with two front seats, that can be adjusted in backrest inclination and longitudinal position, a two-seat rear bench, and a central channel both between the front and the rear seats. The control instrumentation includes a pedalboard with throttle and brake and a steering wheel. The dashboard consists of three monitors of which the instrument cluster (IC) is located behind the steering wheel, and two touch screens, one in the center (Central Display) and the other in front of the passenger seat. The three displays are separated from each other, the central display, protrudes slightly, while the instrument cluster and passenger display are embedded in the dashboard. Interiors also include a lighting system consisting of RGBW LED strips placed in different positions. The lights can be distinguished according to two desired effects: light diffused directly onto the material and light diffused through a diffusion sheath. The configuration of the interior lighting system is composed of three zones: the roof, the central part including the dashboard and the doors (armrests and storage compartments), and the floor. This configuration has been used for interior studies.

The external environment is recreated through a virtual simulation made visible through a 77-inch OLED television set placed one meter from the cockpit, and an immersive audio system consisting of five speakers and a subwoofer, controlled by a 5.1-channel sound card. The speakers are positioned 360 around the platform; three at the front, of which, two are placed to the right and left of the TV, 1m above the ground, and one in the middle on the floor. The other two are located on the back, 1m above the ground and approximately 2.5 m away from the platform. The subwoofer is set centrally at the front.

Physical components also include the instrumentation used to collect real-time physiological data during testing. These include eye-tracking glasses, a wearable device to monitor electrodermal activity, and a helmet to perform neuro-analysis. These instruments communicate either through a wired or wireless connection with the workstation, on which ad hoc software runs to collect real-time data.

In total, the simulation platform is controlled and made interactive by three computers, including one workstation and two on-board computers. The workstation controls the driving simulation, loading scenarios through VI-Grade software, and processing data from the pedals and steering wheel. It is connected to the on-board computer that controls the instrument cluster and central display. The third computer, on the other hand, controls the passenger display.

The workstation also controls the management of the augmented reality viewer. So does the audio system through cable connections to the sound card and the speakers and subwoofer. The workstation is also connected to the lighting system inside the vehicle, consisting of control boards and LED strips.

The onboard computer that controls the instrument cluster and central display also manages the Arduino module. This is necessary to handle the haptic feedback on the central touchscreen display – generated through 4 actuators and the steering wheel pulses that control the instrument cluster interface.

Software Components

When considering software utilized to create interactive prototype it is possible to identify three categories: simulation software, those used for prototyping digital interfaces, and those used in the data collection phase of testing.

For what concern simulation software the lab leverages the Vi-Grade pack as a comprehensive tool to simulate various aspect of the vehicle and of the environment (https://www.vi-grade.com/en/products/vi-worldsim/).

Graphic interface design software are used to create prototype interfaces within the vehicle at multiple levels of interactivity, such as Sketch (https://www.sketch.com/) or Figma (https://www.figma.com) and Protopie Studio. Software such as Protopie Connect and Arduino are used to make the prototypes more interactive and integrated with the physical part of the simulator. TouchDesigner is used to control the simulator's built-in lighting system (https://derivative.ca/).

The software used to collect biometric data are Pupils (https://pupil-labs.com/products/core) and iMotions (https://imotions.com/).

Figure 3. Driving simulator platform from AXD Lab

Main Research Topics and Objectives

The laboratory currently focused on three main areas of interest that required different research processes and methods:

- Comparison of different interaction models in the interface to control the ventilation system.
- Study on the integration of vibrotactile feedback on the central touchscreen.
- Prototyping of a lighting system to develop research on the topic.

These project streams had different objectives, focus and implementation processes, but all involved the use of the simulation platform at different stages, highlighting the flexibility of such a tool in the field of research and design.For example, in the first case, the collaborating company presented itself with the objective of testing two different interfaces to determine which one had a more intuitive and secure interaction. The laboratory took care of the interactive prototyping part of the interfaces, the creation of the protocols for the tests, then conducting the tests and finally analysing the data.

The intervention in the second case, on the other hand, was more extensive, as it involved the downstream study of different types of haptic actuators that could be implemented in a touchscreen, with a consequent study on the creation of haptic feedback. The company's objective was to understand whether haptic feedback could add value to the driving experience, especially from a safety perspective. Consequently, a test protocol was created involving interaction with an interactive prototype while driving and the use of eye-trackers. In this case, the sample studied consisted of 32 participants. The laboratory was then responsible for analysing the data.

The third point, on the other hand, represents a collaboration with the broader reference company. The aim is to explore the opportunities of in-vehicle lighting. The simulator was accordingly extended to integrate a controllable lighting system. Several scenarios were designed during the project, some of which were tested on a small sample for internal feedback.

Conclusions

The paper describes the importance of having research environments in user experience design in the automotive world adequate to respond to the constant evolution this world is experiencing. Digital transformation shapes new requirements in terms of user experience, and the complexity of the levels of interaction enabled within the vehicle requires researchers and designers to have a holistic view on design. Prototyping in this scenario plays a key role because it allows shaping and testing research hypotheses, it must be based on the integration between the physical and virtual worlds that can take place at different levels.

The AXD laboratory establishment at the Politecnico di Milano was created in this context to address these challenges. Designed to support research on the user experience inside the vehicle, the lab provides a dedicated prototyping space equipped with a driving simulator. The platform represents the stage where digital and physical aspects of the experience converge, addressing equal consideration to both.

Furthermore, the lab exemplifies the importance of approaching challenges by bringing together expertise from different academical disciplines within the Politecnico di Milano. By leveraging expertise from diverse fileds, the laboratory fosters a synergistic environment where researchers from various backgrounds converge to tackle complex challenges.

Acknowledgments

This research was supported by the AXD Lab. The authors express their gratitude to all individuals who participated in our study for their valuable time and insights.

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