*Multimodal Technologies and Interaction*

*Article*

# Fostering User Acceptance in Shared Autonomous Vehicles: A Framework for HMI Design

**Ming Yan [1,*], Lucia Rampino [1] and Giandomenico Caruso [2]**

[1] Department of Design, Politecnico di Milano, 20158 Milan, Italy; lucia.rampino@polimi.it
[2] Department of Mechanical Engineering, Politecnico di Milano, 20156 Milan, Italy; giandomenico.caruso@polimi.it
* Correspondence: ming.yan@polimi.it; Tel.: +39-3497014563

**Abstract:** The integration of automated vehicle (AV) technology in public transportation systems offers promising opportunities to improve the flexibility and safety of the traffic environment. However, user acceptance remains a critical challenge in the field of human-machine interaction for the effective deployment of shared autonomous vehicles (SAVs). This study presents a design framework aimed at enhancing user acceptance through human-machine interface (HMI) design tailored to SAVs. The framework is developed in adherence to relevant interaction design principles, following a systematic approach encompassing three key steps: analysis, synthesis, and evaluation. It integrates user acceptance factors into the design process, providing a structured method for designers. The framework was iteratively refined through interviews with three international domain experts; a focus group discussion with 10 researchers and professionals specializing in automotive interaction designers; and a workshop with 30 students and designers. The results demonstrate the framework's ability to guide the development of user-acceptable HMI solutions. The paper concludes by emphasizing the need for further exploration into how user acceptance factors evolve over time and how real-world testing can validate the framework's effectiveness in promoting user acceptance and satisfaction.

**Keywords:** shared autonomous vehicles; design framework; human-machine interfaces; user acceptance

check for updates

**Citation:** Yan, M.; Rampino, L.; Caruso, G. Fostering User Acceptance in Shared Autonomous Vehicles: A Framework for HMI Design. *Multimodal Technol. Interact.* **2024**, *8*, 94. https://doi.org/10.3390/mti8110094

Academic Editor: Martin Tomitsch

Received: 25 August 2024
Revised: 9 October 2024
Accepted: 17 October 2024
Published: 24 October 2024



## 1. Introduction

Transformative changes are occurring in public transportation systems with the introduction of new vehicle technologies such as automated driving, electric vehicles, Internet of Things (IoT), and the emergence of the concept of Mobility as a Service (MaaS) [1]. Autonomous driving technology (AD) plays a transformative role in public transportation by improving traffic flow, reducing accidents, and enhancing sustainability, though its full potential depends on overcoming safety, acceptability, and regulatory challenges in complex urban environments [2]. Shared Autonomous Vehicles (SAVs), a subset of Autonomous Vehicles (AV) [3,4], have the potential to expand existing schedule-based forms of transportation with flexible on-demand mobility options in sustainable and individual solutions. This study focuses on SAVs for transporting people, also known as Automated Shuttle Bus (ASB), as opposed to SAV for transporting goods, which are beyond the scope of our research. The SAE International Standard J3016 (2019) [5] provides a detailed classification of autonomous driving technology levels, stating that levels 1–3 require a human driver, while levels 4 and 5 permit autonomous operation within a defined range or without geographic limitations. The majority of ASB are currently at SAE level 4 and above [6]. Being a medium facilitating information exchange between SAVs and users [7], HMI [8] is responsible for transposing the computer's internal information into external information that users can receive and that can be considered the system's 'face' toward users [9]. Designing HMIs for autonomous driving is an emerging field guided by the principles of user interface design.

Current research on HMI in SAV has shown that precise HMI concepts can enhance interaction between vehicles and users [10], including pedestrians and Vulnerable Road Users (VRUs) [11], thereby increasing user acceptance of AD technology [12]. In user research, the concept of "user acceptance" is utilized to evaluate consumers' behavioral responses and perceived attitudes toward a new technology and product [13]. The definition of "acceptance" is more specific in the research field of AVs, where it represents the favorable attitude and feedback from prospective consumers before and after using the AD technology [14]. Potential users have different behaviors in their acceptance of AD. For consumers with purchasing power, the most prevalent acceptance behavior is having confidence in this technology and being ready to invest in it. As for VRUs [11], acceptance is defined as the degree to which they tolerate the presence of SAVs in an urban road environment. To summarize, the acceptance of AV was determined to be the outcome of four decision-making stages: initial exposure to an automated vehicle, development of a favorable attitude towards it, determination to embrace it, and eventual utilization [15]. Previous literature addressing user acceptance focuses on several factors in a specific design phase (i.e., the analysis phase) without exploring how it fits into the whole design process. More specifically, no systematic research has been conducted to develop a specific HMI design process for SAV to focus on the impact of user acceptance on it.

The HMIs in SAV are classified into interior HMI and exterior HMI (eHMI) according to the different usage scenarios. In terms of interior HMI, academics have given more attention to usability testing than to exploring design development processes. On the other side, most research on eHMI compares the usage of different communication displays, such as the effects on user experience and acceptance of the display technology (projections, LED strips, etc.) and location (front-end, back-end, body-end, etc.), and of the way in which the information is shown (animated icon, arrow, color, number, text, etc.), [16–18]. However, the results vary depending on the experimental setting and method. This underscores the usefulness of HMI design process research in SAV, as user acceptance is a crucial factor.

This research aims to bridge these research gaps to promote and foster user acceptance of SAVs through HMI design. As user acceptance is influenced by various factors, the developed framework intends to propose a systematic and comprehensive approach to guide designers in completing the complex task of designing interactive interfaces that meet user acceptance based on different interaction requirements [19].

After the Introduction section, Section 2 outlines the methodology and research approaches used to develop the design framework. Section 3 presents the framework. Section 4 describes the framework's evaluation process and its practical usage. Finally, Section 5 addresses the obtained findings, constraints, and follow-up prospects.

## 2. Methodology and Research Approach

### *2.1. The Guiding Approach: Research Through Design*

The guiding approach of this study is ***Research through Design (RtD)*** [20], which means doing design as part of doing research. This research follows a conventional trajectory from exploration (proposing hypotheses through theory) to design practice (developing to evaluating) and subsequently to reflection and analysis (validating and adjusting the hypotheses). Specifically, this research concerns designing HMI so that SAV can better transfer information to users. In doing this, authors used the literature to draft a design framework (see Section 3) guiding designers in paying greater attention to user acceptance-related factors during the analysis process, so as to design a user-acceptable HMI for SAV usage scenarios.

### *2.2. Research Process*

Figure 1 presents a summary of the phases in the research process, introducing the research methods applied and the expected findings for each phase. The process was structured into three phases: ***theoretical investigation*** (to define the hypothesis)—

***practical design activities*** (to put into practice the knowledge generated with the theoretical investigation)—***evaluation and verification*** (to verify the hypothesis).

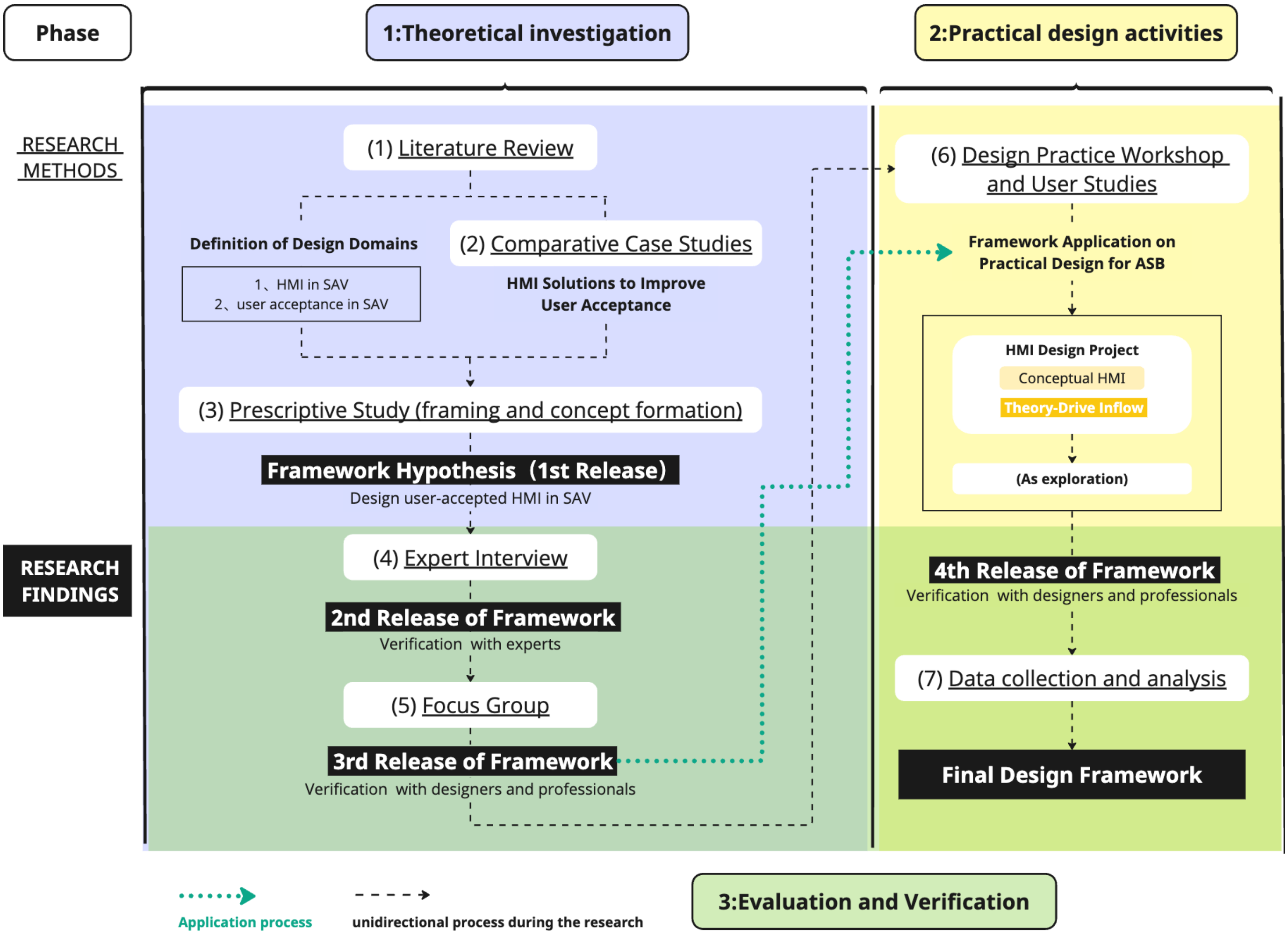


**Figure 1.** Scheme for the overall research methodology with different phases, applied methods, and main findings. The dashed arrows represent a unidirectional process during the research conducted in chronological order, illustrating the progression through the different phases of the study; the dotted green arrow indicates the application of the framework in practical settings.

2.2.1. Theoretical Investigation

1. This phase defined the research boundaries and scope through ***literature review (LR)***. It analyzed the development process of current HMIs and the definition of user acceptance in SAVs. In our earlier work published in *Computer-Aided Design and Applications* (January 2023) [14], we reviewed changes in user interactions with AVs from an HMI perspective and examined user acceptance models in this field. Subsequently, in *Sustainability* (March 2023) [21], we summarized recent developments in HMI systems for SAVs, including both in-vehicle and external interaction scenarios, and outlined key design principles and methods for HMI design. These two studies provide the theoretical framework for the current research.
2. ***Comparative Case Studies*** entailed analyzing differences, similarities, and patterns across multiple cases of HMI with a shared functional focus or design goal [22]. In particular, this study selected the most prevalent Autonomous Shuttle Bus (a specific sub-category of SAV) [23] and analyzed their characteristics by comparing existing HMI solutions for improving user acceptance.

3. The ***Prescriptive Study (PS)*** is a goal-directed academic activity aimed at refining the final concepts and hypotheses generated through preliminary research [24]. Specifically, the goal of this step was to utilize the understanding gained in LR and comparative case studies to determine the most relevant factors to improve the existing situation [25]. A design framework for user-acceptable HMI in SAV was proposed as a hypothesis.
4. Once the first version of the design framework was created, it was improved through ***Expert Interviews*** by incorporating the perspectives of experts.
5. Exploration of HMI's design challenges and the framework hypothesis with designers in a ***Focus Group***. Ten design researchers and professionals with research interests related to HMI for AD were invited to apply the generated framework to define design tasks in two and a half hours. The various suggestions presented by the participants after the event were used to refine the framework guiding the HMI design.

#### 2.2.2. Practical Design Activities

6. The goal of this phase was to apply and validate the framework in a ***Design Practice Workshop***. As the research focus was the Autonomous Shuttle Bus (ASB), the EasyMile EZ10 from France was chosen as the case study due to its widespread use. Designing the HMI for EZ10 was based on investigating promising interactions and functionalities following the three steps: conceptual development, design detailing, and simulation development. The contribution of the design workshop follows the theory-driven inflow to bridge the gap between the (abstract) hypothesis and the (concrete) prototype [26]. After the workshop, a ***User Study*** was conducted with the participants to understand their experience and feedback about using the design framework.

#### 2.2.3. Evaluation and Verification

7. The design framework for user-acceptable HMI in SAV was evaluated and updated through ***Data Collection and Analysis***, which refers to obtaining data from the workshop's participants with quantitative and qualitative methods.

## 3. The First Release of the Design Framework

As we summarized in previous research published in *Sustainability* (March 2023) [21], common design methods in existing studies on HMI design for autonomous vehicles include User-Centered Design (UCD) [27], Participatory Design [28], and Co-Creation [29], etc. These three mainstream approaches can all be characterized by conducting design through ***analysis, synthesis***, and ***evaluation*** in three consecutive steps. The current article builds upon previous research by refining the three-step model for HMI design specific to SAVs. Based on the specific objectives of this study and in conjunction with relevant interaction design principles, a design framework hypothesis focusing on user acceptance of HMI design processes is proposed as shown in Figure 2, after refining the prescriptive study phase through a literature review and comparative case studies [30].

1. ***Analysis*** discovers the design problems by gathering design requirements. In this phase, the model structure proposed by Ekman, F. et al. [19] in 2018 to incorporate trust-related factors into the HMI design process was utilized. However, being the focus of our research on SAVs rather than private vehicles, we considered acceptance-related factors rather than trust-based ones. As a result, when exploring acceptable HMI for SAVs, factors that influence user acceptance must be identified. These factors from the 4P acceptance model proposed by Nordhoff, S. et al. [31] were integrated into a set of specific driving events during three usage phases (preuse, learning, and performance). This step highlights how identifying user acceptance factors is foundational for effective HMI design tailored to SAVs. Detailed descriptions of these factors and their relevance to user acceptance should be included to enhance understanding. It is important to note that not every factor influencing user acceptance

applies to the events within all phases. For example, the factors "interior development" and "remote operation" are not considered during the preuse phase. This is because the collection of explicit and implicit information pertains to two events within the preuse phase, which is aimed at analyzing what occurs prior to the user's first physical interaction with the AD system. Since "interior development" and "remote operation" do not pertain to this stage of user interaction, we did not mark explicit or implicit information for these elements in the corresponding section of the figure. For a detailed illustration of how different factors influence specific events, please refer to Figure 2.

2. ***Synthesis*** phase involves a brainstorming process, which requires designers to generate multiple targeted design approaches and solutions after consolidating user requirements collected during the analysis phase, thus enriching design ideas. Following Morrison et al. (2019) [32] and Zheng et al. (2022) [33], we put forward a four-step process that could assist HMI researchers in developing design concepts: (i) specify the subjects; (ii) target activities; (iii) system interactivity; (iv) design HMI for predefined elements. The four steps should be developed from the user acceptance perspective.
3. ***Evaluation*** involves a comprehensive analysis and assessment of the various design proposals put forward in the synthesis phase to determine their alignment with the expected goals set in the analysis phase. Specifically, it entails using a systematic approach to assess the feasibility, merits, and implementation effectiveness of design proposals, ultimately generating the design outputs. The four steps of the delivery portion of the double-diamond model [34] were integrated into the evaluation phase: (i) transform the top ideas into tangible prototypes, test them, and observe the outcomes; (ii) incorporate the insights gained, reconsider, revise, and retest; (iii) develop, iterate, and repeat as required; (iv) launch the design solution and distribute it to the users.

In conclusion, the analysis phase (1) serves as the foundation by identifying the factors that influence user acceptance, which are essential for guiding the synthesis phase (2). In turn, the synthesis phase generates innovative design solutions based on the insights gained from the analysis. Finally, the evaluation phase (3) assesses these proposed designs against the established acceptance criteria from the analysis, ensuring that the solutions align with user needs and expectations. This interconnected process underscores the importance of iterative feedback and continuous refinement in the HMI design process for autonomous vehicles.

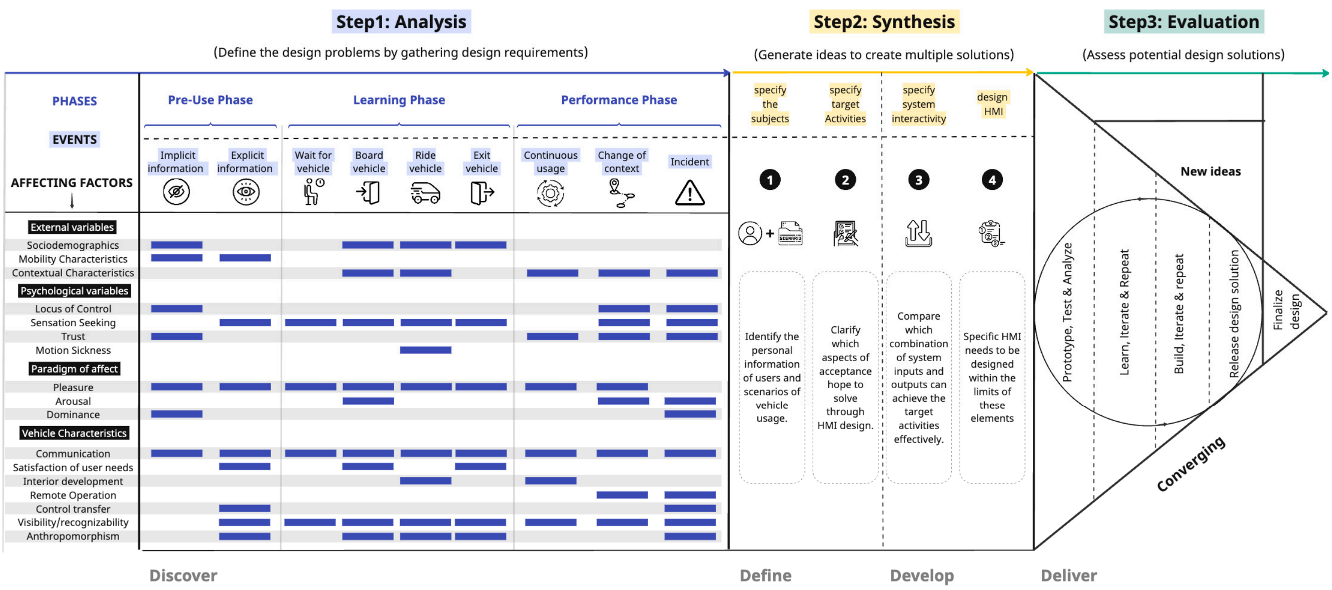


**Figure 2.** The first release of the HMI design framework for shared autonomous vehicles (SAVs).

## 4. Review of the Design Framework

The proposed design framework was reviewed and updated through three methods. First, three international experts were interviewed to investigate their recommendations and perceptions of the framework. Then, a focus group with ten researchers majoring in automotive interaction design was conducted through an online meeting to discuss the second release of the framework. Finally, a design workshop with a test group of 30 design students and designers was carried out specifically for the framework application on practical design for acceptable HMI in ASB.

### *4.1. Expert Interview*

The initial approach involved conducting semistructured interviews with three academic experts from Europe and Asia. The three participants (all male) are from Hochschule Ansbach, Tongji University, and Shanghai Jiao Tong University. Their research focuses on various aspects of autonomous vehicles: user interface design and user experience for digital products; interaction design, information architecture design in vehicle design; colors and fashion trends in vehicle design.

Two of the interviewees suggested the entire process should follow a nonlinear, parallel structure. In addition, the first and second steps should incorporate both divergence and convergence, like the third step. A specific modification proposal was put forward by the professor from Hochschule Ansbach: User groups and scenarios should be determined initially. Consequently, the entire framework was rearranged as follows: the "define" part originally in step 2 was moved to the first step. Moreover, the "define" part and "discover" part in Step 1 are concurrently developed under mutual influence, incorporating both divergence and convergence.

Moreover, when considering the factors affecting user acceptance, the experts suggested allocating more time to gathering data on the changing importance of these factors. Therefore, the framework was revised using the conceptual model for affecting factors introduced by Nordhoff et al. in 2016. A detailed classification of vehicle characteristics was also prioritized, as it is essential to addressing this research inquiry.

### *4.2. Focus Group*

We conducted a focus group via an online meeting with ten design researchers and professionals in this field, during which participants discussed a range of research topics related to user acceptance in SAVs. The 10 participants were: 3 PhD students from Politecnico di Milano (Italy) and Beijing Institute of Technology (China); 3 graduate students majoring in industrial design or interaction design; and 4 professionals who graduated from the design major and are working as project managers or designers in the automotive industry. Prior to the commencement of the focus group, the entire meeting process was planned, and relevant content for the presentation was prepared using the online collaboration tool Miro. During the meeting, participants were encouraged to brainstorm and boldly express their opinions. Ideas and discussions were recorded online through Miro, and all participants' notes were documented and visible to each other. Different sticker colors were used to differentiate the viewpoints of various participants, while the content of verbal discussions was summarized by the moderator and recorded on Miro. This facilitated further discussions between the facilitator and participants on the evolving research topics [35]. The entire focus group lasted for two and a half hours and was recorded using Tencent Meeting (an application developed by Tencent, a company based in Shenzhen, China).

#### 4.2.1. Procedure

The focus group consisted of four separate sessions, with their discussion topics interconnected and progressively structured, including specific design tasks assigned to participants. The entire process is illustrated in Figure 3 below.

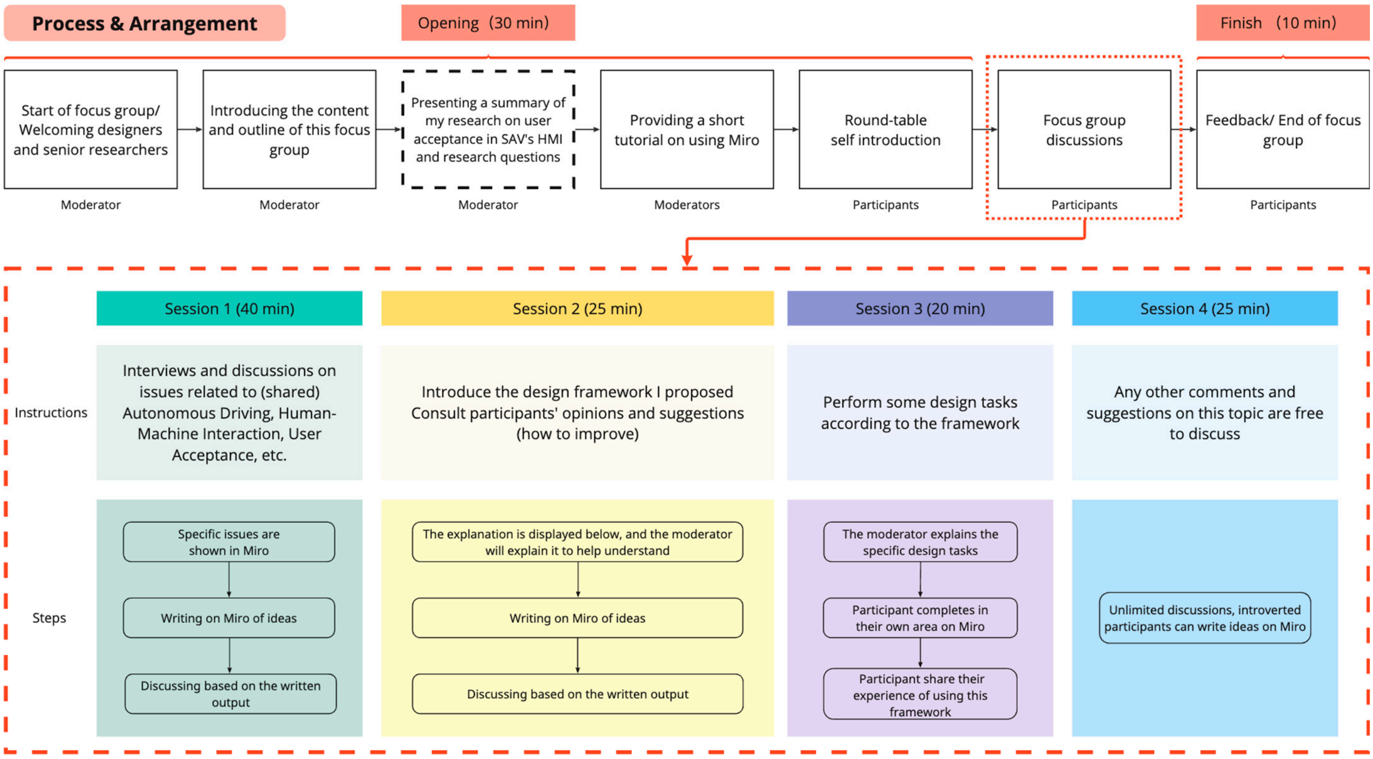


**Figure 3.** Comprehensive arrangement (top) and the four sessions in the focus group. All tutorials before the sessions lasted approximately 30 min, with feedback taking around 10 min after the session to conclude.

(1) ***Session 1:*** This session discusses the existing research related to the three keywords 'Automated shuttle bus', 'User acceptance' and 'human-machine interface' to help participants familiarize themselves with the topic and asks them to express their personal opinions on the problems existing in the current research shown in Miro.
(2) ***Session 2:*** This session involved an introduction to the 2nd release of the design framework. The participants' opinions and suggestions on how to improve it were then collected.
(3) ***Session 3:*** Participants were asked to complete specific design tasks using the design framework to obtain feedback during the trial. In this session, participants focused on the "analysis step" and "synthesis step" of the design framework to verify whether using the framework improves the investigation of the interaction events that can foster user acceptance.
(4) ***Session 4:*** Participants were required to provide constructive feedback on the 2nd release of the framework, focusing on enhancing pertinent concepts. We explicitly directed the participants to consider "user acceptance" during the feedback process, and we also encouraged them to introduce other relevant concepts, such as user experience or trust, to expand the discussion over the many factors influencing user acceptance.

#### 4.2.2. Results and Discussion

The results are presented chronologically based on the four sessions described above. In Session 1, participants shared their understanding and perspectives on HMI design research within this interdisciplinary field. Three participants emphasized the presence of varying degrees of cross-cultural and linguistic barriers in the application of current HMIs in SAVs, which partially hinders user acceptance of this technology in public transportation. Another participant noted that the scope of the target user groups for current HMIs is either insufficiently comprehensive or overly broad, suggesting a need to rethink user classification based on travel behavior and personality traits (such as different MBTI types), highlighting the limitations of traditional personal perspectives. Furthermore, this participant suggested incorporating the "more-than-human" concept, considering urban pets and bicycles carried by passengers within the scope of design.

Following the conclusion of Session 1, participants listened to the moderator's introduction of the framework and posed questions and suggestions for improvement in Session 2. They generally expressed the need for more explanation regarding the affecting factors section, as the current version of the framework did not provide criteria for the selection of variables. Six participants agreed that an index is necessary to assist designers in understanding these factors, with one participant emphasizing that the index should clarify the relationships between different variables and indicate their importance. Additionally, five participants engaged in a vigorous discussion regarding whether the framework should be defined in more abstract or concrete terms. Among those advocating for practicality, three participants stressed the importance of providing a dedicated reference library for designers to guide specific behaviors during the design process. Conversely, two participants argued that the framework should be designed more loosely to allow designers to incorporate their ideas, enhancing their inspirational potential. The remaining five participants did not express opinions on this matter, but during Session 3, after being tasked with specific design activities guided by the framework, they gradually began to formulate their views. Nearly all participants expressed confusion about how to integrate the affecting factors with the various phases of the ride experience. One participant suggested that considerations of user acceptance should also be reflected in the synthesis phase.

Building on the discussions from these three sessions, participants offered more detailed iterative feedback on the second version of the framework in Session 4. They questioned the four classification criteria for the affecting factors, recommending the inclusion of additional factors beyond the four categories. They also expanded on external variables and vehicle characteristics. Furthermore, one participant provided insights on how to validate the framework, suggesting that comparisons with other classical design processes could serve as a validation method. This also indicated the limitations of existing validation methods, such as virtual reality and expert interviews, prompting us to consider more effective and enriched approaches for this activity.

In summary, based on the focus group results, we delivered the 3rd release of the framework. Specifically, we developed an index to help designers better understand the affecting factors related to user acceptance when using the framework in the discovery part of the "analysis step". Additionally, criteria for variable selection were added to the index, as well as an indication of how the size/length of the different color blocks used to represent each influence factor are determined.

### *4.3. Design Workshop*

Under the guidance of the third release of the framework, a design workshop was conducted with students from different majors and designers from different car manufacturers in China. The task was to design the interaction design scheme for future traffic scenarios. Their diverse academic backgrounds enabled them to analyze the design task from various perspectives, such as industrial/product/interaction design, visual communication, landscape architecture, technology and IT, materials science, and consumer psychology.

#### 4.3.1. Workshop Design

The workshop, with the assistance of an educational institution called "Alien Design Studio" in China, recruited 30 participants aged 20–27 (21 females and 9 males), comprising 16 students from design disciplines—10 undergraduate students and 6 graduate students—5 graduate students from other disciplines, and 9 designers currently employed at automotive companies. The workshop spanned one month from February to March 2024, divided into 6 sessions—Define, Discover, Develop, Deliver, and Finalize (see Figure 4), each requiring 8 h of participation. After the workshop, a combined quantitative and qualitative data collection method was used to gather feedback from the participants on their design projects developed through the framework, as well as to collect their insights regarding the guiding role of the framework.

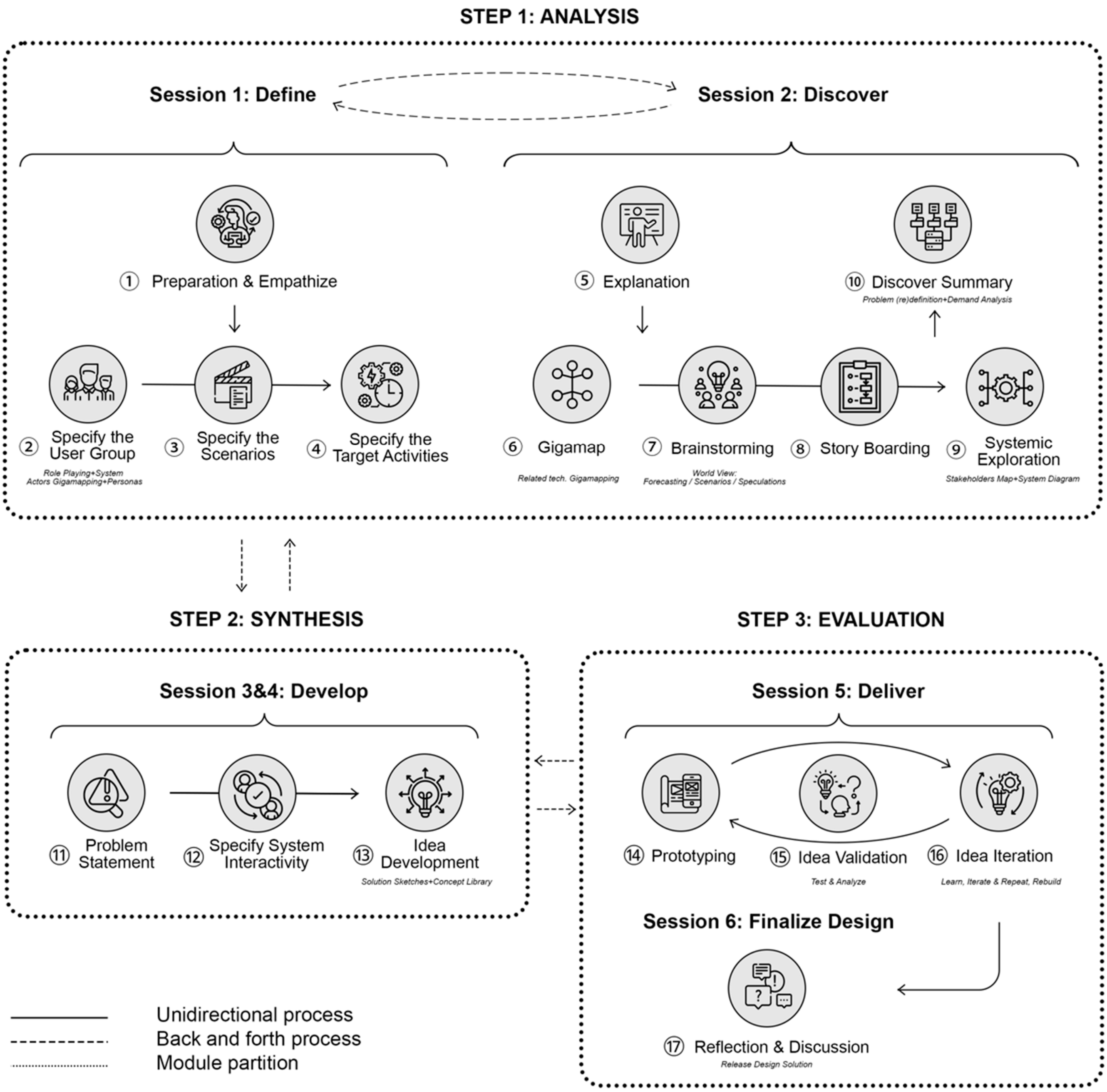


**Figure 4.** The design workshop process.

### 4.3.2. Process and Tools

Prior to the workshop commencement, participants were divided into five groups, each consisting of six individuals. They were assigned the responsibility of conducting research on the background of the study area to gain an understanding and identify the potential issues in the current HMI design status for SAVs in order to complete the "***Preparation & Empathize***" step.

In the first session of the workshop, we guided participants to complete the defining phase of the analysis step in the design framework. Firstly, all groups were required to ***Specify the User Group***, establishing empathy through role-playing [36]. Each team member selected a role and temporarily stepped out of the designer's role, viewing the world from the perspective of different stakeholders with whom the SAV would interact to reveal their underlying needs. All team members summarized the user roles they focused on to create a system actors gigamapping, thus constructing their team's user personas. Subsequently, we asked the participants to ***Specify the Scenarios and Target Activities*** with design needs and necessity determined for the typical users they focused on, as illustrated in Figure 5.

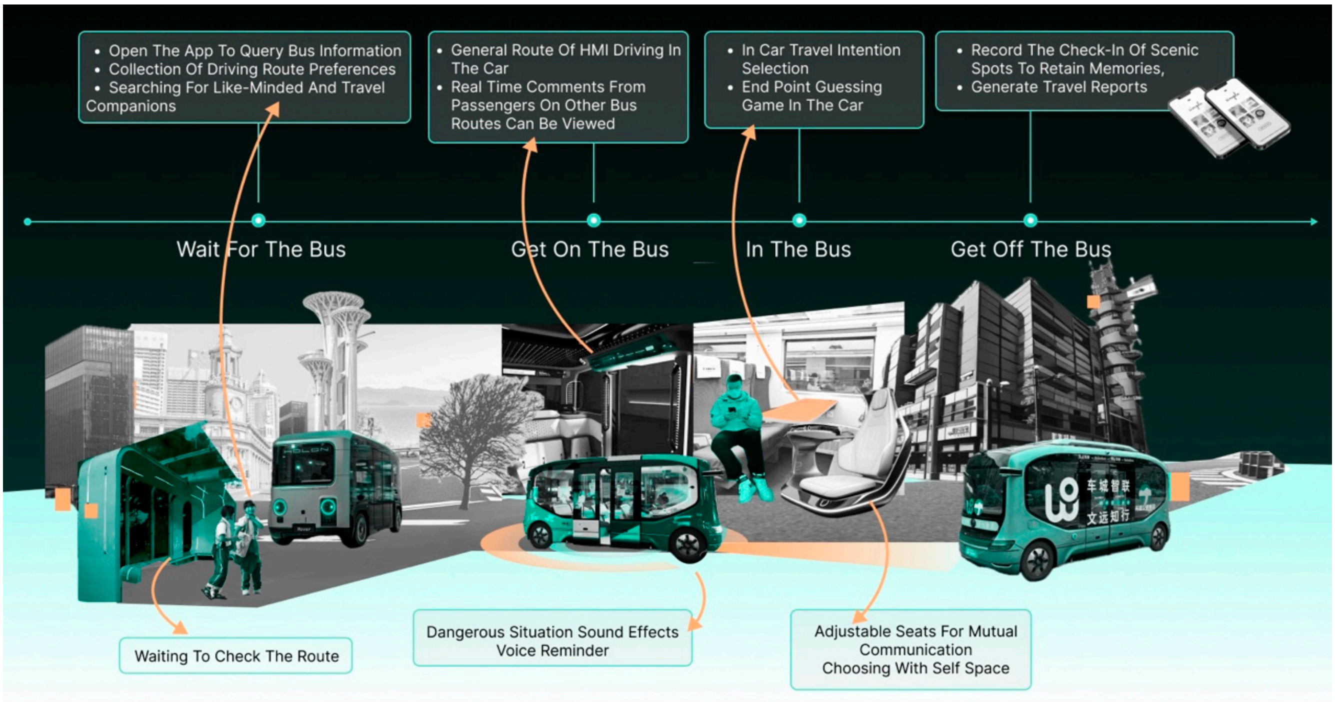


**Figure 5.** The focus scenarios and target activities specified in Group 5's example.

In the second session of the workshop, we guided participants to complete the discovery phase of the analysis. First, in the ***Explanation,*** we introduced the factors related to user acceptance that need to be considered and the different phases and events to pay attention to in the future traffic scenario. Second, participants were asked to research and enrich the ***Gigamap*** on trends related to technologies. Thirdly, based on Gigamap, all groups were asked to establish their own worldview and complete ***Brainstorming***. Fourthly, they did the ***Story Boarding*** with the previously selected roles and used scenarios to explain the most relevant (for them) affecting factors, touchpoints, and insights. Fifth, through the system diagram, other relevant stakeholders were discovered and analyzed to complete the ***Systematic Exploration*** (see Figure 6). Finally, each team was asked to complete the ***Discover Summary*** through problem (re)definition and demand analysis.

After completing the 'analysis', sessions 3 and 4 were conducted to complete the second step 'synthesis'. The teams first defined the problem and hypothesis statement to complete the ***Problem Statement***. Then, each group was required to generate design concepts based on the identified design pain points. In doing that, they were required to ***Specifying the System Interactivity***, i.e., defining the specific input (user behavior and physiological states) and output (visual, auditory, haptic, olfactory, and multichannel) methods. Finally, group members completed the ***Idea Development*** through brainstorming and sketches to form an array of design concepts for the group. It is also worth mentioning that both in Step 1 and Step 2 groups were required to continuously diverge and converge to refine the solutions.

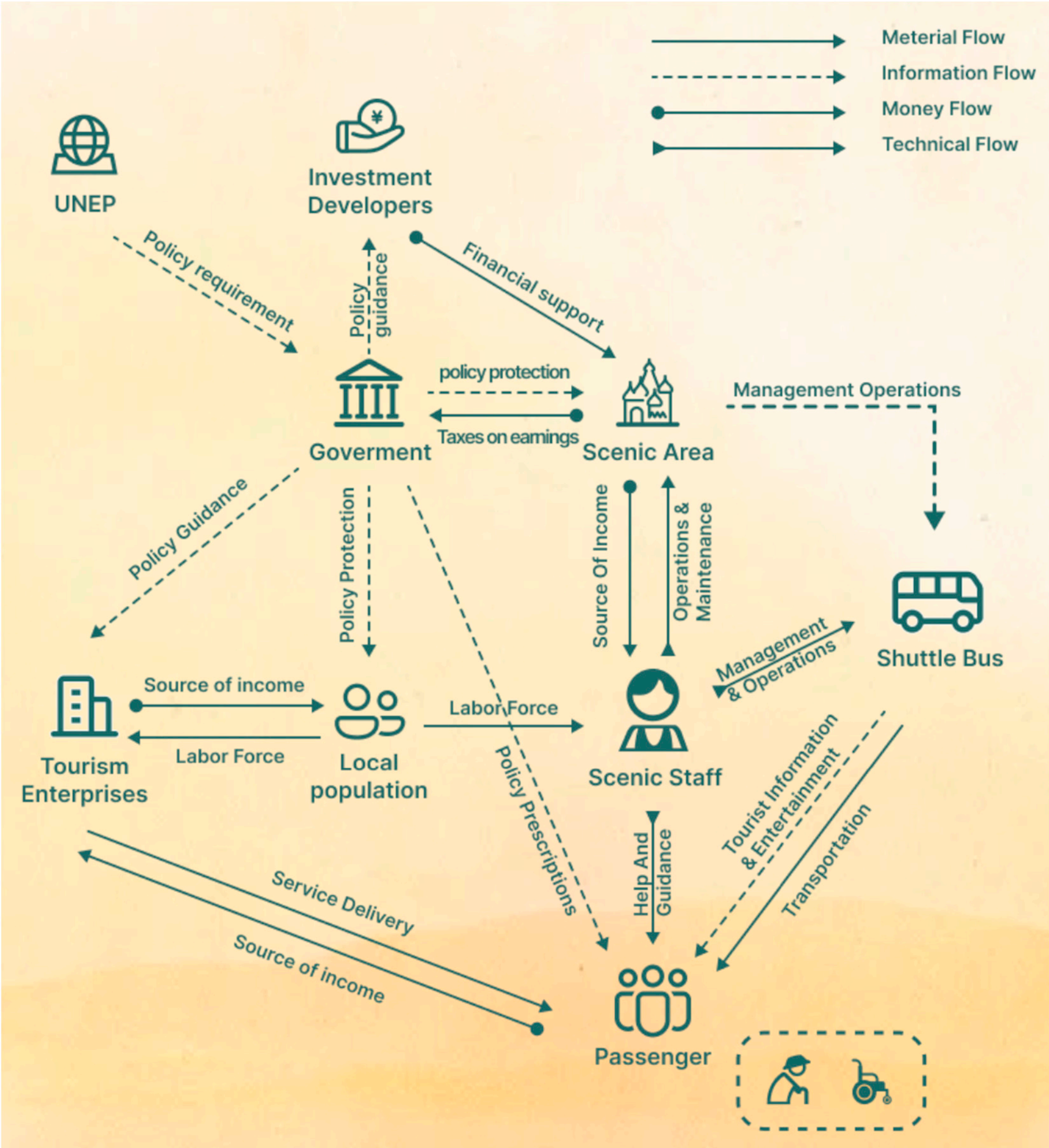


**Figure 6.** System diagram from Group 1 facilitating systematic exploration.

The final step is evaluation. This step is completed through sessions 5 and 6. In the "delivery" phase, all groups were required to create prototypes based on their design solutions. Then, they had to select appropriate testing and analysis methods to validate the generated prototypes. If any issue was identified during the validation process, further iteration of the design proposals would be conducted through the "Learn, Iterate, Repeat, and Rebuild" steps. In summary, session 5 revolved around "***Prototyping***", "***Idea Validation***", and "***Idea Iteration***". Finally, in session 6, each group presented their design solutions to the other teams, engaged in mutual reflection and discussion of their proposals, and considered how to iterate. Deepening their design proposals based on the feedback from other groups enabled each team to ***Finalize the Design***.

During the workshop, each group completed the design task guided by the design framework described in Section 3 (see Figure 7 for example). Despite focusing on different subjects and target activities, all proposed future interaction scenarios prioritize user acceptance. They generated interaction design solutions through reflection and consideration of these scenarios.

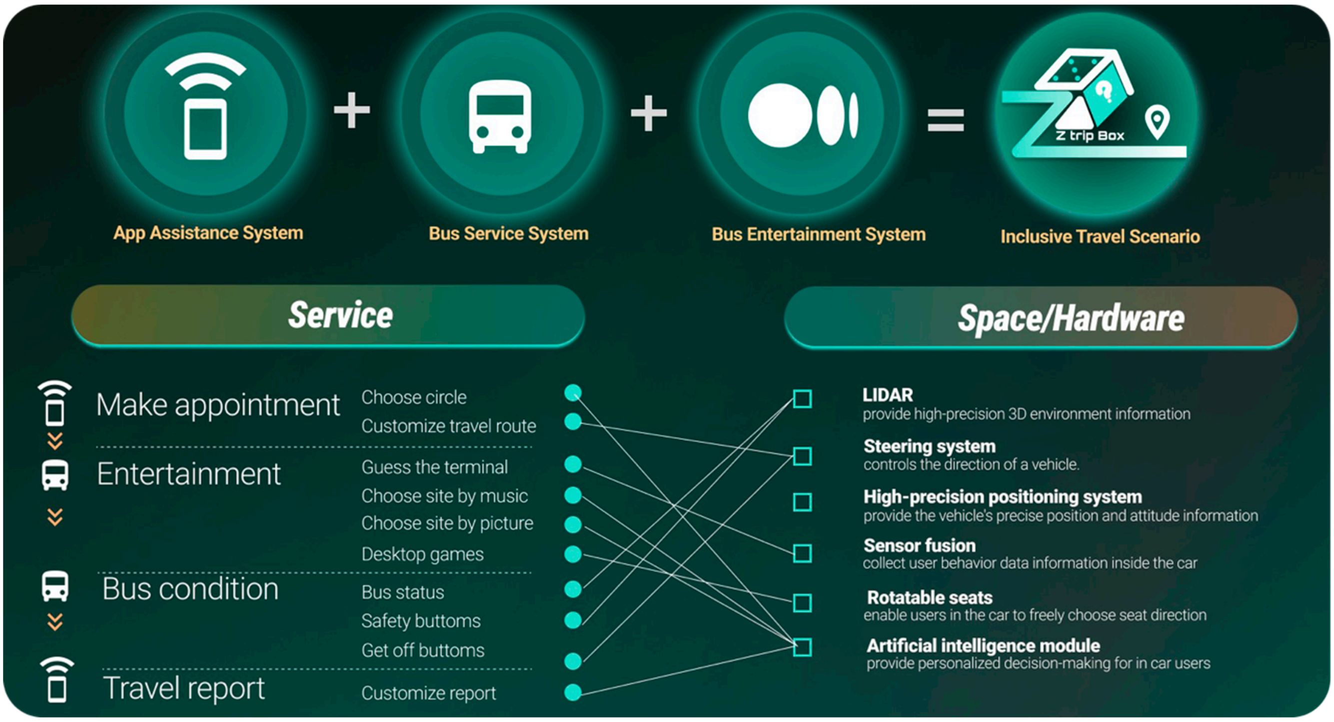


**Figure 7.** The design proposal details presented by Group 5 include specific interaction mediums, service types, spatial/hardware structures, etc.

#### 4.3.3. Data Collection and Analysis

The workshop provided new feedback and reflections on our design framework. Our focus was to explore whether the proposed framework and the underlying design process can stimulate designers' creativity and improve their awareness of the importance of stimulating user acceptance. After the workshop, a mixed-method approach was used to collect qualitative [37] and quantitative data.

Using Google Forms, an online questionnaire [38], designed bilingually in Chinese and English, including single-choice and multiple-choice questions analyzed using Likert scales [39], as well as open-ended questions, was conducted to gather participants' feedback. Although answering the questionnaire was voluntary and had no incentives, a total of 30 valid responses were received. This permitted us to collect qualitative insights.

The questionnaire consisted of three parts. The first part briefly introduced the survey's purpose and collected participants' personal information, including gender, age, field of study, and primary responsibilities within the team, etc. The second part used multiple-choice questions and 5-piont Likert scales to gather respondents' perceptions of using the design framework during the workshop. Figure 8 shows that participants are generally satisfied with the design framework; they acknowledge its practicality and believe that it helped their design thinking approach to some extent. Furthermore, participants found that the design framework can serve as an appropriate design approach to help them enhance user acceptance of HMI design for SAVs. This effect is most pronounced in the discovery phase during the analysis steps and in the development phase during the synthesis steps. Figure 9 depicts this. However, the participants suggested adding a definition of each factor that may influence user acceptance and some advice on how to handle it in the design process. This means that we should provide the framework with a manual instruction to guide designers on its usage.

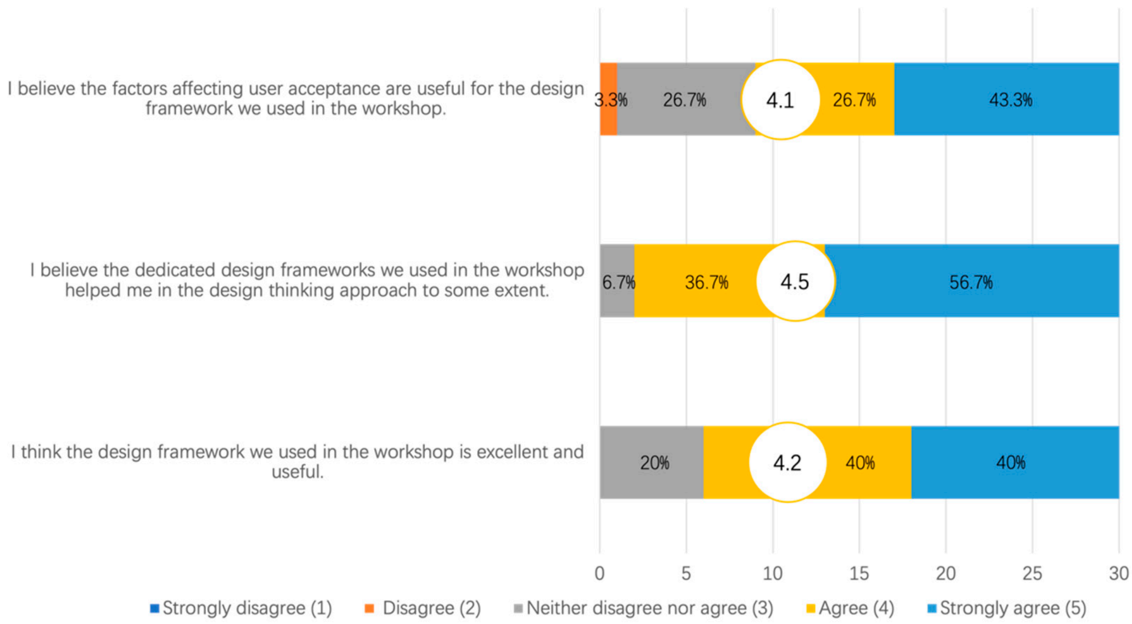


**Figure 8.** Results from the online questionnaire using Likert scales: respondents' perceptions on the design framework.

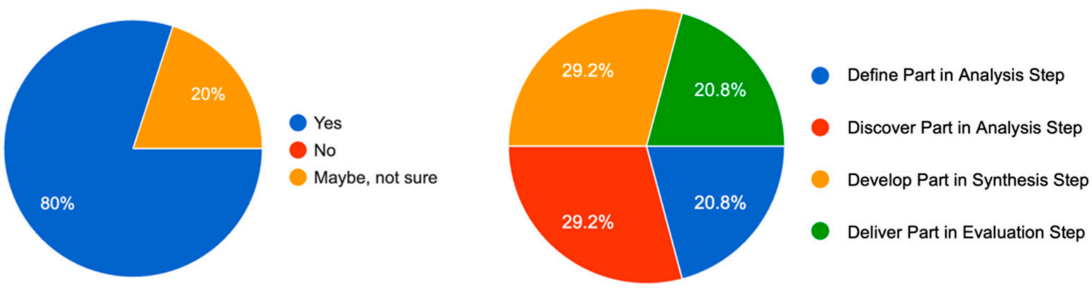


**Figure 9.** Results from the online questionnaire: Participants think the design framework can be used as a suitable design method to improve user acceptance in designing HMI for SAV (**Left**). Note: No participants selected the 'no' option for this question, so it is not red displayed in the graph; Respondents' perceptions on which stage is the effect most apparent (**Right**).

The third section employs a combination of multiple-choice questions and open-text responses to gather participants' viewpoints on the influence of interactive design activities and tools utilized during the workshop. Figures 10 and 11 visually display the results from the online questionnaire, representing the participants' viewpoints. Participants have the liberty to choose any combination of activities/tools. In the scenario where all 30 participants select the same activity, the statistical representation would reveal a 100% response rate for that activity. Moreover, the percentage depicted in the graph signifies the ratio of survey respondents who opted for a specific activity relative to the total survey participants (30 individuals). Overall, the survey results indicate that participants are highly attentive to specifying the target user groups, usage scenarios, and particular activities during the execution of specific design tasks. However, after the design phase, they are more inclined to further explore how the prototype development and testing processes contribute to iterating and validating the design outcomes.

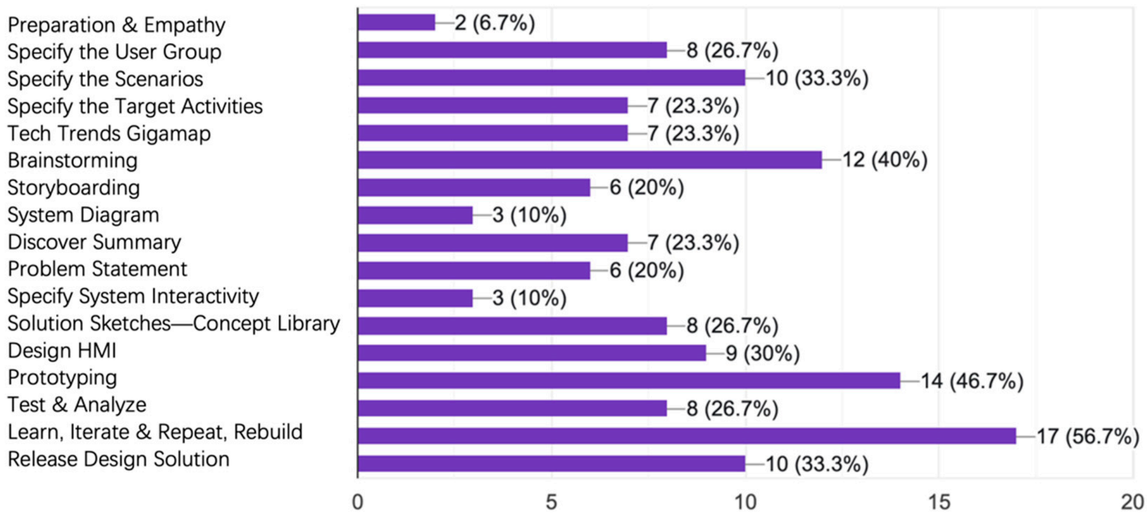


**Figure 10.** Activities, tools, and methods that participants think are exciting and interesting.

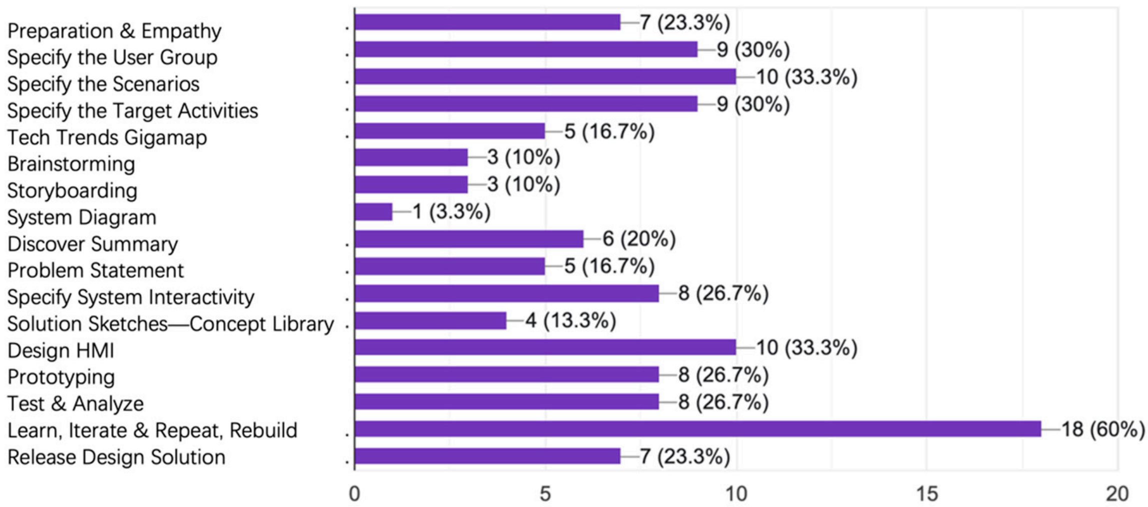


**Figure 11.** Activities, tools, and methods that participants want to be explored further.

### *4.4. Result*

The three activities—expert interviews, focus groups, and workshops—collectively contributed to a comprehensive evaluation of the framework from multiple perspectives. The expert interviews provided critical insights into the theoretical underpinnings of the framework, highlighting the need for a nonlinear structure and the incorporation of various user groups and scenarios, thereby refining the initial process and structure of the framework. Focus groups facilitated a deeper understanding of user perspectives, revealing concerns about cross-cultural barriers and the necessity of a more detailed classification of affecting factors. This feedback was instrumental in iterating the framework's structure and enhancing its applicability. Finally, the workshop served as a practical application of the framework, allowing participants to engage with it directly and assess its effectiveness in stimulating creativity and improving user acceptance awareness. The mixed-methods approach utilized during the workshop further enriched the evaluation by collecting quantitative and qualitative data, enabling a comprehensive assessment of the framework's usability and impact on design practices. Together, these activities not only validated the framework but also informed its evolution through iterative feedback and practical testing.

## 5. The Final Version of the Design Framework

The design framework for user-acceptable HMI in SAV was evaluated and updated through the three activities mentioned above. Four releases of the design framework were created during the process. Figure 12 shows the final version.

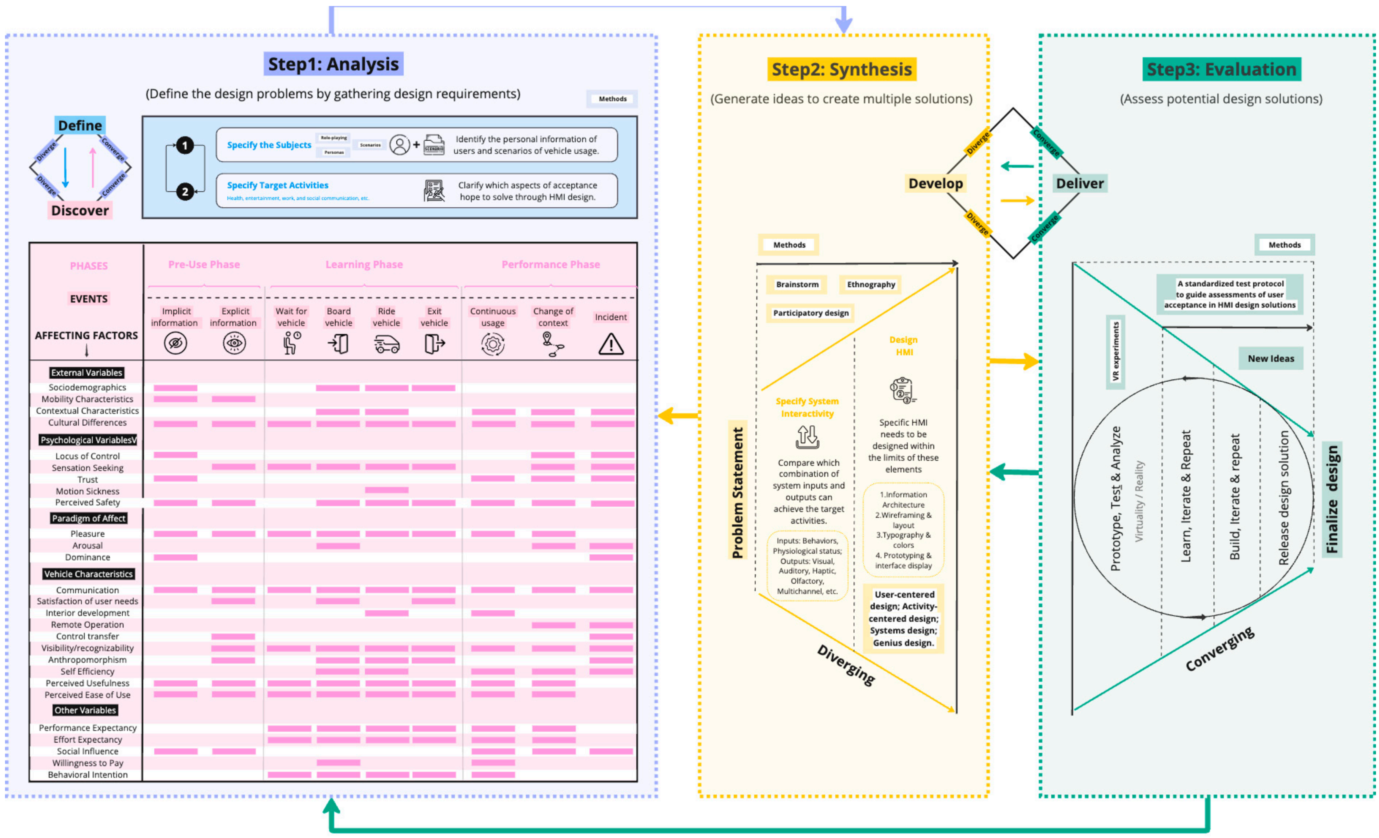


**Figure 12.** The final version of the HMI design framework for shared autonomous vehicles (SAVs).

Compared to the first release of the design framework described in Section 3, the specific subjects and target activities defined in the synthesis step have been anticipated for the analysis step. Additionally, factors influencing user acceptance have been expanded. Specifically, we provided manual instructions (see Appendix A) to guide designers in using the design framework and offered an index (see Appendix B) to help them understand the potential factors influencing user acceptance. The index includes standardized selection variables and explains how to determine the size and length of different colored blocks used to represent each influencing factor. Importantly, like the third step, also the first and second steps involve divergence and convergence. Finally, we noticed that, in the evaluation step, the design assumptions completely missed the connection with the specific topic of user acceptance of SAV in HMI. Therefore, we are currently working to define a standardized test protocol for this step and to conduct empirical assessments using virtual reality (VR) technology to demonstrate whether the HMI solutions meet the relevant requirements for user acceptance.

To sum up, the final version of the design framework adheres to the four stages of the Double Diamond model [40]—define, discover, develop, and deliver—clearly illustrating how steps (1), (2), and (3) contribute to the overall process. In the analysis phase, the discovery and definition stages mutually reinforce each other in a continuous cycle, facilitating the early design analysis. During the discovery stage, the SAV scenario is divided into nine distinct events, which are further categorized into three phases: Pre-Use Phase, Learning Phase, and Performance Phase. The 27 factors that potentially influence user acceptance are then evaluated within these events and classified into five main categories: external variables, psychological variables, vehicle characteristics, paradigm of affect, and other variables. This method enables designers to develop a comprehensive understanding of typical SAV interactions and promotes deeper reflection on how user acceptance may affect specific interactions. The define stage focuses on identifying users, usage scenarios, and target interaction activities to gather design requirements and clearly articulate the design problem. Subsequently, the synthesis step emphasizes the development of multiple HMI design solutions, addressing the problem statement through the specification of system interactivity. After generating HMI solutions, the evaluation step assesses the feasibility and effectiveness of these solutions, utilizing VR technology for simulation and testing, either preparing the concept for launch or fostering the creation of new design ideas.

## 6. Discussion and Conclusions

The objective of the presented research was to foster the user acceptance dimensions of HMI in SAVs. To achieve this, a design framework was defined and tested. More specifically, the following activities were carried out sequentially.

- Defining user acceptance-affecting factors related to SAVs.
- Determining how to measure user acceptance of SAVs' HMI.
- Investigating the types and design processes of existing HMIs in SAVs.
- Developing a framework for HMI design, integrating those acceptance-affecting factors into the design process.
- Executing user research (expert interviews, focus groups, and design workshops) to test the framework.

The proposed framework revolves around the application of AD technology in shared transportation scenarios, providing guidance for industry practitioners developing HMI systems for SAVs. Through testing and evaluation, the practicality of this framework has been demonstrated, as it can assist designers in gaining a more comprehensive understanding of how user acceptance of SAV is established and how various human-machine interaction events impact user acceptance.

Despite these promising outcomes, there are several limitations to the current study that should be acknowledged. First, while the framework incorporates 27 identified factors affecting user acceptance, it remains unclear how these factors interact with one another over time in complex real-world scenarios. The static nature of the framework may not fully account for the dynamic and evolving interactions between users and HMIs during the longer-term use of SAVs. Additionally, the current research primarily focuses on the early-stage design process, leaving gaps in understanding how these acceptance-affecting factors change throughout the product life cycle or post-deployment.

Furthermore, due to designers' varying backgrounds and habits, their interpretations of the acceptance-affecting factors mentioned in this framework, as well as their understanding of how these factors interact with each other, may differ. Therefore, another limitation lies in the framework's inherent flexibility. While it is intentionally kept "loose" as a design guide rather than a prescriptive manual, this flexibility could potentially result in inconsistent applications of the framework across different design teams, leading to variable design outcomes. Moreover, regarding the evaluation process, the reliance on expert interviews, focus groups, and workshops, although valuable, introduces potential biases, as these methods predominantly capture expert and designer perspectives. The end users of SAVs, who will ultimately determine the success of the HMI, were not directly involved in the testing phases.

To address these limitations, further exploration is necessary. Future research should aim to determine how different acceptance-affecting factors interact to create appropriate levels of user acceptance, especially as users become more familiar with SAVs. The framework's adaptability to evolving technologies and user expectations must also be investigated, as advancements in autonomous driving technology could render some factors obsolete or introduce new considerations. Moreover, it is essential to prioritize end-user testing and validation in real-world environments to better assess the practical effectiveness of the framework in achieving user acceptance. Expanding evaluation to include physical prototypes or in situ testing can provide more robust insights into the framework's applicability and reliability.

Looking ahead, future iterations of the framework should not only incorporate interactive design principles but also consider other methodologies, such as systems design, speculative design, and inclusive design. This multifaceted approach can enhance the framework's capacity to address broader sociotechnical systems and diverse user needs.

In conclusion, the design framework proposed in this paper integrates analytical, synthesis, and evaluation steps based on interactive design principles to present an HMI design process aimed at enhancing user acceptance. However, some factors in this framework are relatively difficult to define, and it is challenging to determine how each factor individually affects user acceptance, as well as how these factors interact over time. We plan to build and test a series of virtual and physical prototypes designed under the guidance of this framework, combining these with user-centered evaluations. By conducting comprehensive in-field testing and considering diverse user groups, the framework can truly fulfill its potential to enhance user acceptance of SAVs.

**Author Contributions:** Conceptualization, M.Y.; methodology, M.Y.; formal analysis, M.Y.; investigation, M.Y.; resources, M.Y.; data curation, M.Y.; writing—original draft preparation, M.Y.; writing—review and editing, L.R. and G.C.; visualization, M.Y.; supervision, L.R. and G.C.; project administration, M.Y.; funding acquisition, M.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** This study was conducted according to the guidelines of the Declaration of Helsinki. The ethical review and approval were waived for this study due to the fact that all humans participating only had to participate in the online workshop and follow-up semistructured interviews, and prior to that, they were informed that they would participate in scientific research, carry their own risks, and stay anonymous. No animals were involved.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data is contained within the article; further inquiries can be directed to the corresponding author.

**Acknowledgments:** The online public workshops in this project recruited participants with the support of an educational institution in China called "Alien Design Studio." The author would like to express gratitude to this institution for its support of this design practice workshop and to thank all participants in the focus group discussions and expert interviews for their assistance in this research. The current study was carried out at Politecnico di Milano's i.Drive (Interaction of Driver, Road, Infrastructure, Vehicle, and Environment) Laboratory (http://www.idrive.polimi.it/, accessed on 1 May 2024).

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A. Manual Instruction for the Framework

This manual provides instructions for conducting specific design practice tasks guided by the design framework. The objective is to ensure a consistent and accurate design process across different design teams in completing the design tasks. The three steps in the framework—Analysis, Synthesis and Evaluation—can further be divided so to reach a total of six sessions—Define, Discover, Develop, Deliver, and Finalize Design.

Instructions (see Figure A1):

1. Preparation & Empathize: Conduct a comprehensive background investigation into the research topic to identify and evaluate potential issues in the current state of Human-Machine Interface (HMI) design for Shared Autonomous Vehicles (SAVs). Employ empathy techniques through role-playing [37], where each team member

adopts a specific role, temporarily stepping out of their designed role to gain perspectives from various stakeholders interacting with the SAV.

2. Specify the User Group: Summarize and document the user roles that the team has focused on and create a gigamap to illustrate the system actors involved. This process aids in constructing detailed user personas for the team.
3. Specify the Scenarios: Define the diverse use cases or interaction contexts in which the system will operate. This includes outlining the specific environments, user groups, and contexts relevant to the HMI of the SAV.
4. Specify the Target Activities: Identify the primary tasks users will perform while interacting with the system. This involves understanding the specific actions users need to undertake, such as requesting a ride, selecting a destination, adjusting in-vehicle settings, or receiving notifications.
5. Explanation: Analyze factors related to user acceptance and identify the critical phases and events to monitor in future traffic scenarios.
6. Brainstorming: Utilize design tools such as related technologies, gigamaps, and storyboards to facilitate divergent brainstorming aimed at constructing future worldviews.
7. Systemic Exploration: Review the future scenarios previously created and analyze them using stakeholder maps and system diagrams. This involves examining complex systems or problems by considering the interactions and interdependencies among their various components to gain a comprehensive understanding of the system dynamics.
8. Discover Summary: Redefine potential design issues and challenges that may arise in the future scenario. Conduct a needs analysis to identify the critical requirements and expectations of users and stakeholders.
9. Problem Statement: Provide a concise overview of the specific design problem or challenge the project seeks to address. Explain the impact of the problem on users and outline the design objectives for resolving the issue. Identify gaps or deficiencies in the current HMI that hinder user acceptance and interaction effectiveness.
10. Specify System Interactivity: Define how users will interact with the system and how the system will respond to user inputs. This includes detailing interaction types, such as input and output methods, user flows, and response mechanisms. Consider elements like task sequences, feedback systems, and system behavior in user interactions.
11. Idea Development: Encourage creative thinking and exploration of a range of possible solutions without immediate judgment or constraints. Use methods such as solution sketching, creating a concept library, or conducting group discussions to foster innovative approaches.
12. Prototyping: Develop low-fidelity prototypes, such as sketches or wireframes, to visualize and test initial design concepts. These early prototypes help gather feedback and provide insights into how users may interact with the system.
13. Idea Validation: Conduct usability testing with prototypes to assess their effectiveness and gather user feedback. This process helps identify strengths and weaknesses in the design concepts, enabling informed adjustments and improvements.
14. Idea Iteration: Revisit and refine ideas based on the results of testing and feedback. Iteratively enhance the design through multiple prototype versions to progressively improve functionality, user acceptance, and overall design quality.
15. Reflection and Discussion: Develop the final design solution by refining details, such as visual design, interaction patterns, and system responses. Engage in reflection and discussion to ensure that the design meets the intended objectives and effectively addresses user needs.

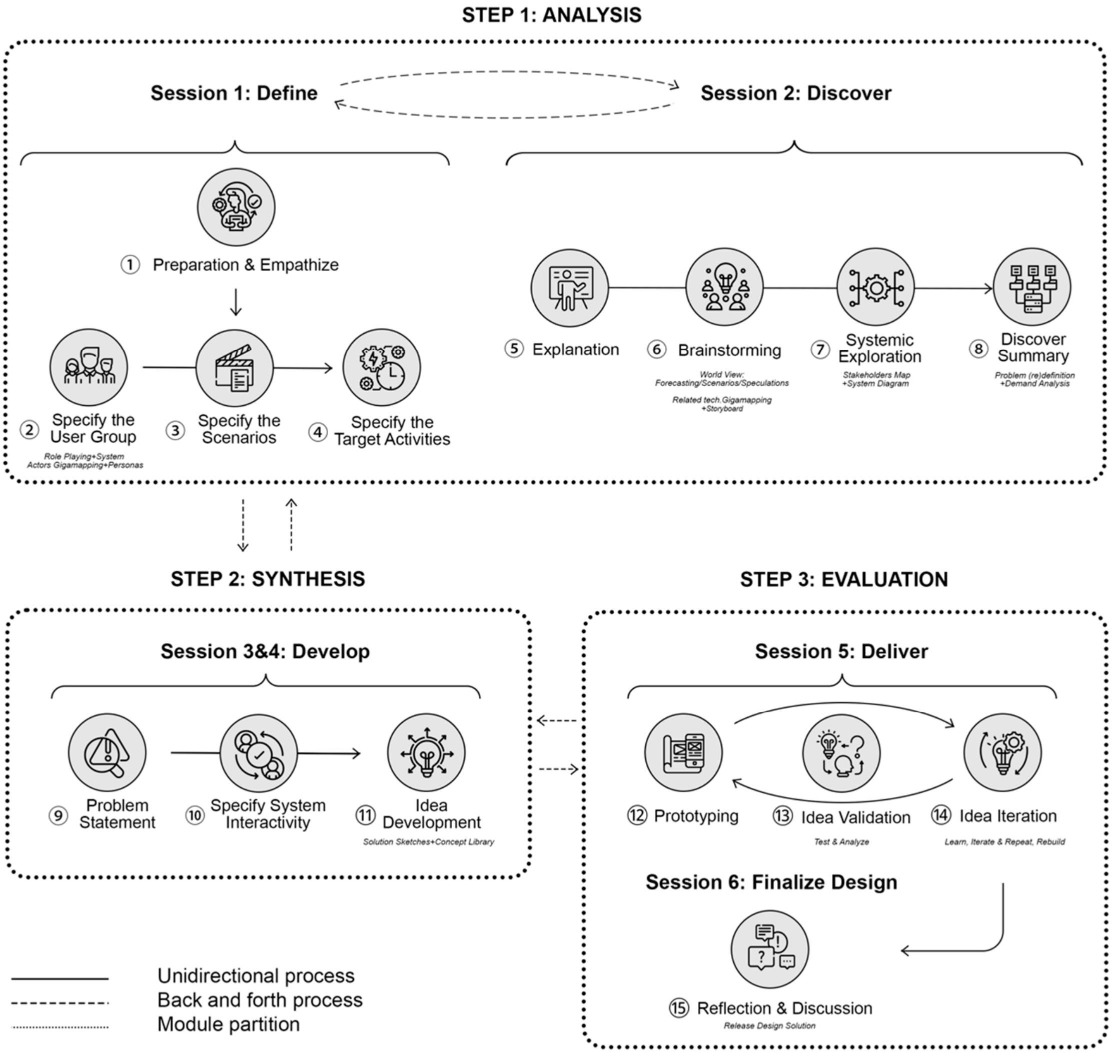


**Figure A1.** The manual instruction followed with appropriate processes and design methods.

## Appendix B. Index Defining User Acceptance-Affecting Factors

1. **External variables** encompass demographic, social, and environmental factors that influence user acceptance of SAVs. These are largely contextual and societal, influencing the broader attitude toward SAV adoption.
    - Sociodemographics: Attributes such as age, gender, income, education, and occupation. These factors can determine the level of familiarity with technology, financial capacity, and openness to adopting SAVs.
    - Social Influence: The impact of societal norms, peer groups, and community opinions on an individual's decision to adopt SAVs. Positive endorsements from trusted figures can increase acceptance.
    - Mobility Characteristics: Individual travel behaviors and preferences, such as reliance on public transport, vehicle ownership, and frequency of travel, which can affect how SAVs are perceived as a transportation option.
    - Contextual Characteristics: Includes location-specific factors like urban versus rural environments, infrastructure readiness, and service availability, which can impact the feasibility and attractiveness of SAVs.
    - Cultural Differences: Cultural attitudes toward technology, innovation, and transportation methods that can vary between regions, affecting how SAVs are received and adopted in different cultural contexts.

2. **Psychological variables** are internal to the user, rooted in personal attitudes, traits, and cognitive perceptions that affect the acceptance of SAVs.
    - Locus of Control: Individuals' belief in their ability to control events and outcomes. Those with an internal locus of control may be more critical of SAVs, while those with an external locus may accept the technology more.
    - Sensation Seeking: A personality trait where users seek novel and stimulating experiences. Sensation seekers may be more willing to try SAVs as they offer a novel driving experience.
    - Trust: Confidence in the technology and its providers. Higher levels of trust in the safety and reliability of SAVs increase user acceptance.
    - Motion Sickness: Physical discomfort experienced by some users when riding in autonomous vehicles. Addressing motion sickness concerns can enhance comfort and acceptance.
    - Self-Efficacy: Users' belief in their ability to effectively interact with and control the SAV. Higher self-efficacy increases confidence and acceptance of the system.
    - Perceived Safety: Users' belief that SAVs provide a level of safety comparable to or greater than conventional vehicles. Safety concerns are a major factor in determining acceptance.
    - Perceived Usefulness: The degree to which users believe that SAVs will improve their travel efficiency and overall mobility experience.
    - Perceived Ease of Use: The simplicity and intuitiveness of interacting with the SAV system, from booking a ride to using in-vehicle interfaces. A user-friendly design increases acceptance.
3. **Vehicle Characteristics** focus on the design, functionality, and interaction of the SAV itself. These factors directly influence the user experience and acceptance.
    - Communication: The ability of the SAV to communicate effectively with users, pedestrians, and other vehicles. Clear and transparent communication builds trust.
    - Satisfaction of User Needs: The degree to which the SAV meets the practical and emotional needs of the user, such as comfort, convenience, and personalization.
    - Interior Development: The design of the vehicle's interior, including ergonomics, space, and comfort, which significantly affect the user experience.
    - Remote Operation: The capability of controlling the SAV remotely in certain situations, which provides users with a sense of security and reliability.
    - Control Transfer: The ability of the system to seamlessly transfer control between the autonomous system and the user (if applicable), ensuring a smooth and safe transition.
    - Visibility/Recognizability: How easily users and other road users can recognize the SAV and understand its intentions, which affects safety perception.
    - Anthropomorphism: The degree to which the SAV system or interface is designed to have human-like characteristics (e.g., voice, behavior), which may affect user comfort and acceptance.
4. **Paradigm of Affect** considers emotional responses to SAVs, which play a significant role in user experience and acceptance.
    - Pleasure: The degree of enjoyment or satisfaction users feel when using an SAV. Positive emotional experiences can enhance acceptance.
    - Arousal: The level of excitement or stimulation users feel when interacting with SAVs. Higher arousal may be linked to sensation seekers, while low arousal may be preferred by users seeking comfort.
    - Dominance: The feeling of control users have over the interaction with SAVs. High dominance (a sense of control) can lead to greater acceptance, especially if users feel empowered by the system.

5. **Other Variables** include expectancy factors and behavioral intentions, which influence the user's motivation and willingness to adopt SAVs.
    - Performance Expectancy: The belief that using an SAV will help the user achieve better performance in terms of travel time, convenience, or productivity.
    - Effort Expectancy: The perceived ease with which users can learn and use the SAV system. Lower perceived effort leads to higher acceptance.
    - Willingness to Pay: Users' readiness to pay for SAV services, which can be influenced by perceived value, affordability, and alternatives available.
    - Behavioral Intention: The user's intention to use SAVs in the future, is often influenced by prior experiences, perceptions of ease of use, and trust in the system.

## References


1. Wong, Y.Z.; Hensher, D.A.; Mulley, C. Mobility as a Service (MaaS): Charting a Future Context. *Transp. Res. Part Policy Pract.* **2020**, *131*, 5–19. [CrossRef]
2. Orieno, O.H.; Ndubuisi, N.L.; Ilojianya, V.I.; Biu, P.W.; Odonkor, B. The future of autonomous vehicles in the U.S. Urban landscape: A review: Analyzing implications for traffic, urban planning, and the environment. *Eng. Sci. Technol. J.* **2024**, *5*, 43–64. [CrossRef]
3. Lim, H.S.M.; Taeihagh, A. Autonomous Vehicles for Smart and Sustainable Cities: An in-Depth Exploration of Privacy and Cybersecurity Implications. *Energies* **2018**, *11*, 1062. [CrossRef]
4. Hu, J.; Bhowmick, P.; Arvin, F.; Lanzon, A.; Lennox, B. Cooperative Control of Heterogeneous Connected Vehicle Platoons: An Adaptive Leader-Following Approach. *IEEE Robot. Autom. Lett.* **2020**, *5*, 977–984. [CrossRef]
5. SAE J3016 Automated-Driving Graphic. Available online: https://www.sae.org/site/news/2019/01/sae-updates-j3016-automated-driving-graphic (accessed on 17 March 2023).
6. Autonomous Vehicles: Computer Science & IT Book Chapter | IGI Global. Available online: https://www.igi-global.com/chapter/autonomous-vehicles/260171 (accessed on 29 September 2024).
7. Burns, C.G.; Oliveira, L.; Thomas, P.; Iyer, S.; Birrell, S. Pedestrian Decision-Making Responses to External Human-Machine Interface Designs for Autonomous Vehicles. In Proceedings of the 2019 IEEE Intelligent Vehicles Symposium (IV), Paris, France, 9–12 June 2019; pp. 70–75.
8. Bischoff, S.; Ulrich, C.; Dangelmaier, M.; Widlroither, H.; Diederichs, F. Emotion Recognition in User-Centered Design for Automotive Interior and Automated Driving. In Proceedings of the Stuttgarter Symposium für Produktentwicklung SSP 2017, Stuttgart, Germany, 28–29 June 2017.
9. Bevan, N.; Carter, J.; Earthy, J.; Geis, T.; Harker, S. New ISO Standards for Usability, Usability Reports and Usability Measures. In *Human-Computer Interaction. Theory, Design, Development and Practice*; Lecture Notes in Computer Science; Springer: Cham, Switzerland, 2016; Volume 9731, pp. 268–278. [CrossRef]
10. Stadler, S.; Cornet, H.; Novaes Theoto, T.; Frenkler, F. A Tool, Not a Toy: Using Virtual Reality to Evaluate the Communication Between Autonomous Vehicles and Pedestrians. In *Augmented Reality and Virtual Reality: The Power of AR and VR for Business*; tom Dieck, M.C., Jung, T., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 203–216; ISBN 978-3-030-06246-0.
11. Tabone, W.; de Winter, J.; Ackermann, C.; Bärgman, J.; Baumann, M.; Deb, S.; Emmenegger, C.; Habibovic, A.; Hagenzieker, M.; Hancock, P.A.; et al. Vulnerable Road Users and the Coming Wave of Automated Vehicles: Expert Perspectives. *Transp. Res. Interdiscip. Perspect.* **2021**, *9*, 100293. [CrossRef]
12. Schuitema, G.; Steg, L.; van Kruining, M. When Are Transport Pricing Policies Fair and Acceptable? *Soc. Justice Res.* **2011**, *24*, 66–84. [CrossRef]
13. Yan, M.; Geng, W.; Hui, P. Towards a 3D Evaluation Dataset for User Acceptance of Automated Shuttles. In Proceedings of the 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Shanghai, China, 25–29 March 2023; pp. 89–93.
14. Yan, M.; Rampino, L.; Caruso, G. User Acceptance of Autonomous Vehicles: Review and Perspectives on the Role of the Human-Machine Interfaces. *Comput.-Aided Des. Appl.* **2023**, *20*, 987–1004. [CrossRef]
15. Pigeon, C.; Alauzet, A.; Paire-Ficout, L. Factors of Acceptability, Acceptance and Usage for Non-Rail Autonomous Public Transport Vehicles: A Systematic Literature Review. *Transp. Res. Part F Traffic Psychol. Behav.* **2021**, *81*, 251–270. [CrossRef]
16. Xing, Y.; Lv, C.; Cao, D.; Hang, P. Toward Human-Vehicle Collaboration: Review and Perspectives on Human-Centered Collaborative Automated Driving. *Transp. Res. Part C Emerg. Technol.* **2021**, *128*, 103199. [CrossRef]
17. Rouchitsas, A.; Alm, H. External Human–Machine Interfaces for Autonomous Vehicle-to-Pedestrian Communication: A Review of Empirical Work. *Front. Psychol.* **2019**, *10*, 2757. [CrossRef]
18. Dicianno, B.E.; Sivakanthan, S.; Sundaram, S.A.; Satpute, S.; Kulich, H.; Powers, E.; Deepak, N.; Russell, R.; Cooper, R.; Cooper, R.A. Systematic Review: Automated Vehicles and Services for People with Disabilities. *Neurosci. Lett.* **2021**, *761*, 136103. [CrossRef] [PubMed]
19. Ekman, F.; Johansson, M.; Sochor, J. Creating Appropriate Trust in Automated Vehicle Systems: A Framework for HMI Design. *IEEE Trans. Hum.-Mach. Syst.* **2018**, *48*, 95–101. [CrossRef]

20. Stappers, P.J.; Giaccardi, E. Research through Design. In *The Encyclopedia of Human-Computer Interaction*; Soegaard, M., Friis-Dam, R., Eds.; The Interaction Design Foundation: Aarhus, Denmark, 2017; pp. 1–94.
21. Yan, M.; Lin, Z.; Lu, P.; Wang, M.; Rampino, L.; Caruso, G. Speculative Exploration on Future Sustainable Human-Machine Interface Design in Automated Shuttle Buses. *Sustainability* **2023**, *15*, 5497. [CrossRef]
22. van den Beemt, A.; Vázquez-Villegas, P.; Gómez Puente, S.; O'Riordan, F.; Gormley, C.; Chiang, F.-K.; Leng, C.; Caratozzolo, P.; Zavala, G.; Membrillo-Hernández, J. Taking the Challenge: An Exploratory Study of the Challenge-Based Learning Context in Higher Education Institutions across Three Different Continents. *Educ. Sci.* **2023**, *13*, 234. [CrossRef]
23. Bartlett, L.; Vavrus, F. Comparative Case Studies: An Innovative Approach. *Nord. J. Comp. Int. Educ. NJCIE* **2017**, *1*, 5–17. [CrossRef]
24. Blessing, L.T.; Chakrabarti, A. Prescriptive Study: Developing Design Support. In *DRM, a Design Research Methodology*; Blessing, L.T.M., Chakrabarti, A., Eds.; Springer: London, UK, 2009; pp. 141–180; ISBN 978-1-84882-587-1.
25. Kuechler, B.; Vaishnavi, V. On Theory Development in Design Science Research: Anatomy of a Research Project. *Eur. J. Inf. Syst.* **2008**, *17*, 489–504. [CrossRef]
26. Koskinen, I.; Zimmerman, J.; Binder, T.; Redstrom, J.; Wensveen, S. *Design Research Through Practice: From the Lab, Field, and Showroom*; Elsevier: Amsterdam, The Netherlands, 2011; ISBN 978-0-12-385503-9.
27. Giacomin, J. What Is Human Centred Design? *Des. J.* **2014**, *17*, 606–623. [CrossRef]
28. Carvalho, S.; Gluck, A.; Quinn, D.; Zhang, M.; Li, L.; Groves, K.; Brinkley, J. An Accessible Autonomous Vehicle Ridesharing Ecosystem. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* **2021**, *65*, 342–346. [CrossRef]
29. Riener, A.; Schlackl, D.; Malsam, J.; Huber, J.; Homm, B.; Kaczmar, M.; Kleitsch, I.; Megos, A.; Park, E.; Sanverdi, G.; et al. Improving the UX for Users of Automated Shuttle Buses in Public Transport: Investigating Aspects of Exterior Communication and Interior Design. *Multimodal Technol. Interact.* **2021**, *5*, 61. [CrossRef]
30. Mohammad Mithun, A.; Bakar, Z. Analysis of Human Machine Interaction Design Perspective—A Comprehensive Literature Review. *Int. J. Contemp. Comput. Res.* **2017**, *1*, 31–42.
31. Nordhoff, S.; van Arem, B.; Happee, R. Conceptual Model to Explain, Predict, and Improve User Acceptance of Driverless Podlike Vehicles. *Transp. Res. Rec. J. Transp. Res. Board* **2016**, *2602*, 60–67. [CrossRef]
32. Morrison, G.R.; Ross, S.J.; Morrison, J.R.; Kalman, H.K. *Designing Effective Instruction*; John Wiley & Sons: Hoboken, NJ, USA, 2019; ISBN 978-1-119-46593-5.
33. Zheng, Y.; Ren, X. Developing a Multimodal HMI Design Framework for Automotive Wellness in Autonomous Vehicles. *Multimodal Technol. Interact.* **2022**, *6*, 84. [CrossRef]
34. Gustafsson, D. Analysing the Double Diamond Design Process Through Research & Implementation. Master's Thesis, Aalto University, Espoo, Finland, 2019.
35. Peng, C.; Horn, S.; Madigan, R.; Marberger, C.; Lee, J.D.; Krems, J.; Beggiato, M.; Romano, R.; Wei, C.; Wooldridge, E.; et al. Conceptualising User Comfort in Automated Driving: Findings from an Expert Group Workshop. *Transp. Res. Interdiscip. Perspect.* **2024**, *24*, 101070. [CrossRef]
36. Sevaldson, B. Visualizing Complex Design: The Evolution of Gigamaps. In *Systemic Design: Theory, Methods, and Practice*; Jones, P., Kijima, K., Eds.; Translational Systems Sciences; Springer: Tokyo, Japan, 2018; pp. 243–269; ISBN 978-4-431-55639-8.
37. Ranasinghe, C.; Holländer, K.; Currano, R.; Sirkin, D.; Moore, D.; Schneegass, S.; Ju, W. Design for Services in Complex System Contexts: Introducing the Systemic Design Toolkit. In Proceedings of the Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA, 25 April 2020; ACM: New York, NY, USA; pp. 1–8.
38. Faas, S.M.; Baumann, M. Yielding Light Signal Evaluation for Self-Driving Vehicle and Pedestrian Interaction. In Proceedings of the Advances in Intelligent Systems and Computing; Springer: Berlin/Heidelberg, Germany, 2020; Volume 1026, pp. 189–194.
39. Aburbeian, A.M.; Owda, A.Y.; Owda, M. A Technology Acceptance Model Survey of the Metaverse Prospects. *AI* **2022**, *3*, 285–302. [CrossRef]
40. Kochanowska, M.; Gagliardi, W.R. The Double Diamond Model: In Pursuit of Simplicity and Flexibility. In *Perspectives on Design II: Research, Education and Practice*; Raposo, D., Neves, J., Silva, J., Eds.; Springer International Publishing: Cham, Switzerland, 2022; pp. 19–32; ISBN 978-3-030-79879-6.