MASTER THESIS - USER EXPERIENCE DESIGN

AI-Driven Context-Adaptive User Interfaces for in-car Infotainment Systems

Design, Prototypical Implementation and Evaluation

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Imagine.....🤔💭

→ process **dynamic variables**
→ figures out how **this specific combination** of variables **affects you** in **this specific moment**
→ intelligently **adapts the GUI**

🌙 🚗 ⛽ 🌧️

It's Night you're Driving at Low fuel in Poor weather

dim non-essential elements

boost contrast of important components

emphasize nearby open gas stations within range

🚗 🤔 🌆 🚦 😰

Driving in an unfamiliar city in heavy traffic & nervous

simplifies map, suppresses non-critical info

enlarge navigation realted text and icons

reduces animations

Examples of possible adaptations

Motivation

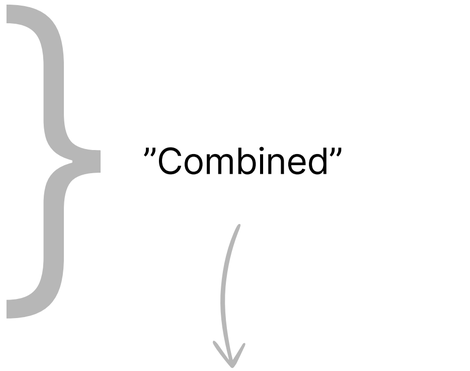
Contextual Variables *[7]*

Continuous & dynamic variables

speed, traffic, weather conditions, time of day, driving behavior, presence of pedestrians or nearby vehicles, planned maneuvers, etc.

Stable / slowly changing variables

media content preferences, interaction styles, calendar, frequently visited locations, long-term usage patterns, vehicle-specific info



meaningful & personalized experiences

Research Gaps

Current Research in infotainment adaptivity

1. **Carried out with:**

   Mock-ups or Rule-based systems *[2, 4, 6]*,
   Traditional machine/deep learning techniques *[1, 5]*

   } ***Modern LLMs?***

2. **These Addresses:**

   What to Show.
   When to Show.

   } ***Detailed adaptation?***

3. **We found:**

   Transformer-driven adaptivity algorithms with technical measurements *[3]*

   } ***UX?***

Goal: Create something that..

Leverages modern LLMs
+
Scalable & Functional
+
Real-time

Controls detailed GUI adaptations

Measure its effect on UX and Safety

Research Questions

and hypotheses.

AI-assembled: AI-Driven, context-adaptive GUI assembly

Pre-assembled: Pre-designed GUI screens (baseline)

How do AI-assembled and pre-assembled GUIs for in-car infotainment....

RQ 1

..differ in terms of **usability, clarity,** & **value?**

RQ 2

..affect perceived **cognitive load, distraction** & **situational awareness?**

RQ 3

..affect **percieved adaptivity?**

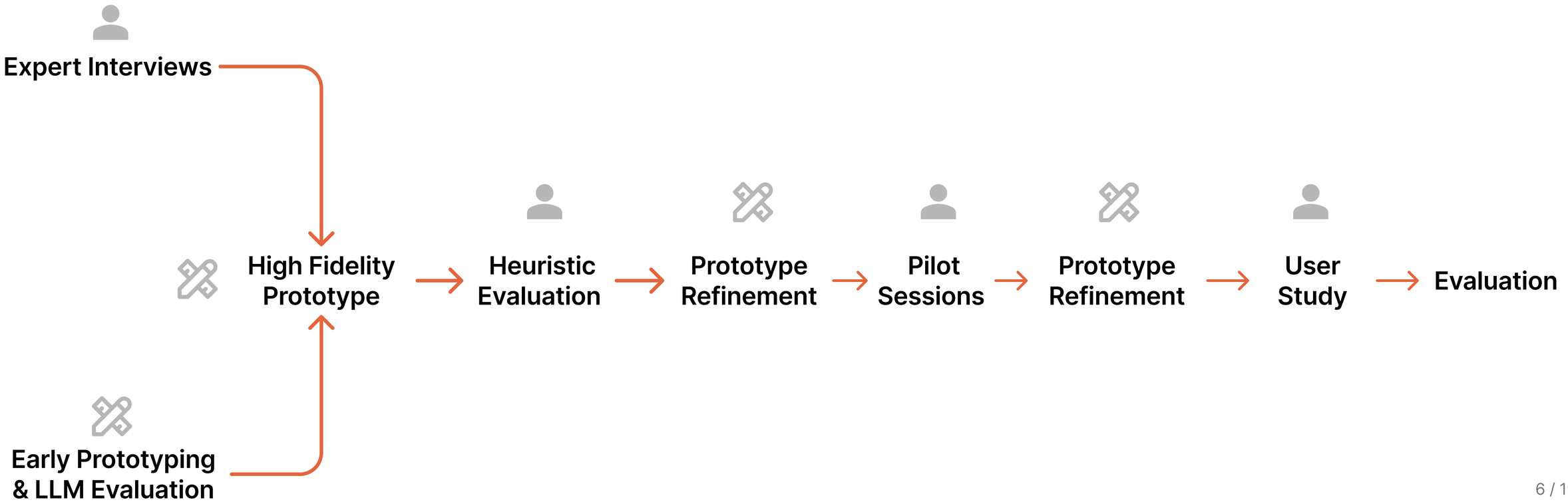
H1: AI-assembled system performs as well as or better than the pre-assembled system.

H2: AI-assembled UI results in equal or lower cognitive load and distraction, and equal or higher situational awareness compared to pre-assembled UI

H3: AI-assembled UI provides significant improvement in perceived contextual adaptivity compared to a pre-assembled UI

Human centered

Research-Through-Design



Core Formative Findings

Expert Interviews

- 7 Professionals
- Across 5 Departments
- Semi-Structured
- Thematic Clustering involving 2 researchers

Functions hidden under or split across different levels
→ Frustration / Confusion

Existing adaptive features based on deterministic, rule-based logic

(adding more use-cases = manual work)

High Interest in the topic
Industry actively moving towards the vision of “use-case-less“ design

Core Formative Findings

LLM Evaluation via Early Prototype

2.5-pro Overall Winner Ø 14s

(diff. reasoning tokens)

Opus-4

(diff. reasoning tokens)

GPT-5 Best Adaptivity Ø > 60s

GPT-5 mini

(high, mid, low)

8 GUI components

+

Narrowly defined System Prompt

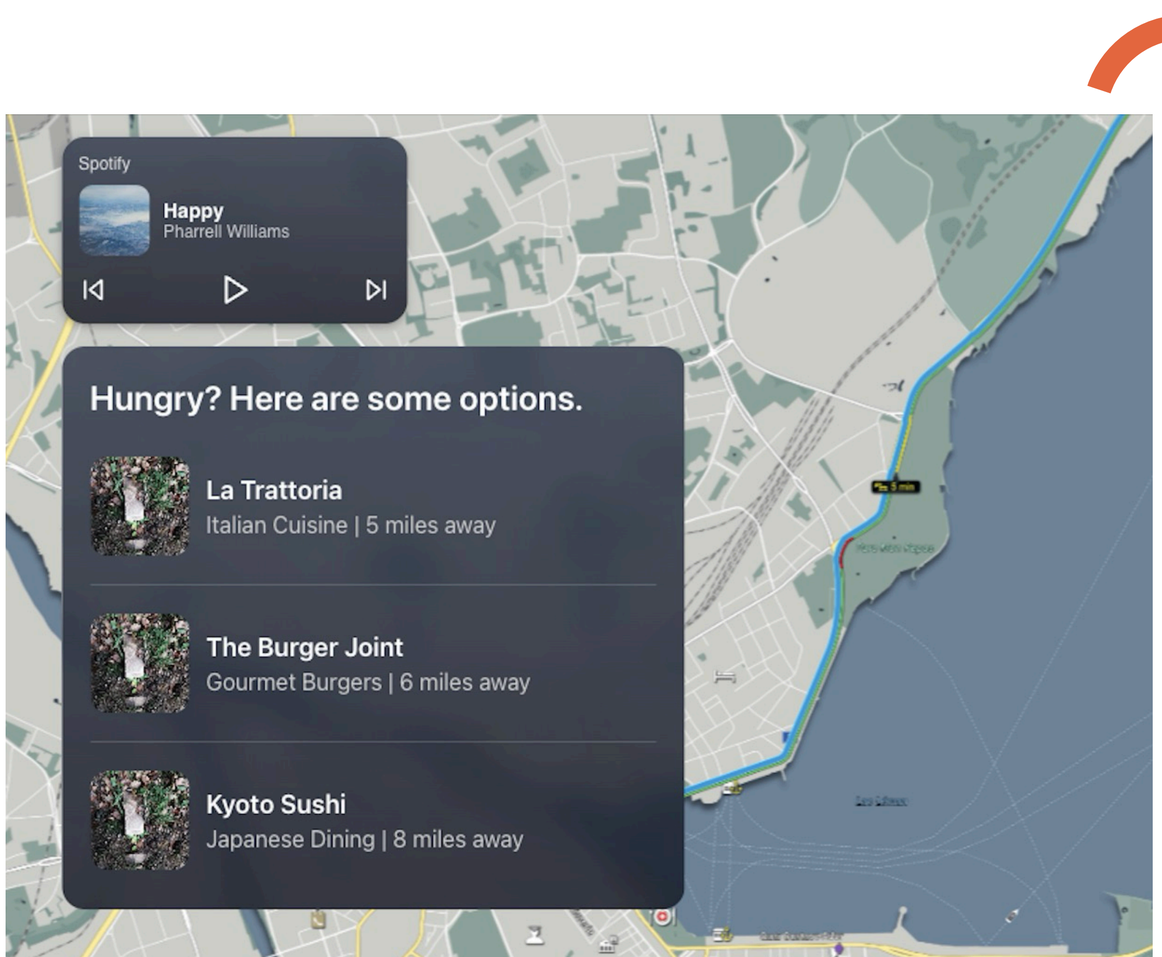
Initial user input
(”Bored and Hungry”)

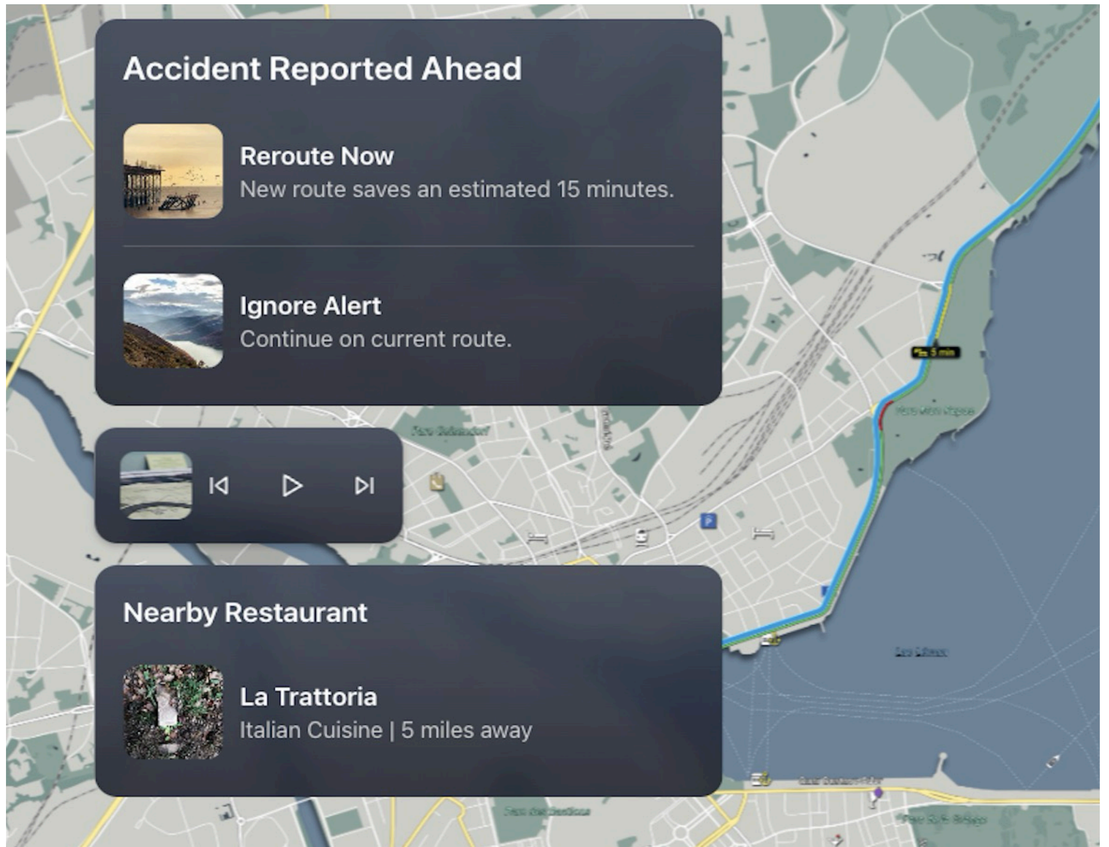
+

Manual contextual trigger
(”Accident ahead”)

Core Formative Findings

LLM Evaluation via Early Prototype (GUI adaptation using Gemini 2.5 Pro)





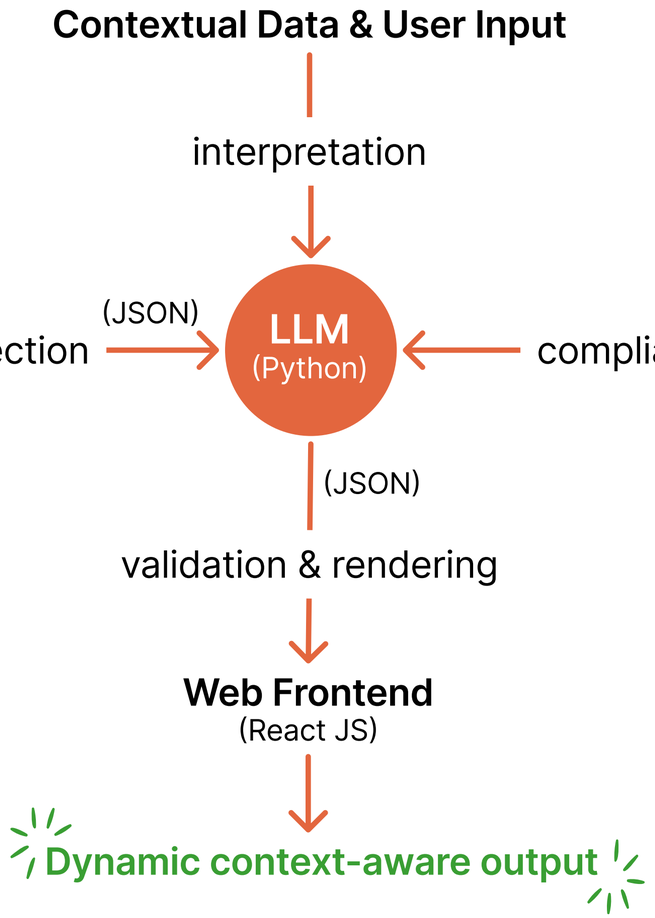
The Final Recipe

Constrained AI-based Assembly Architecture

Atomic-level, Pre-designed GUI Component Library

This allows us to:

- preserves **Brand Identity**
- comply with **safety guidelines**



System Prompt

Identity, Capabilities & Objective
Layout specifications
Safety Principles
Usability Heuristics
Driver Profile
Output Instructions (JSON)

Push to Talk Integration

Ability to choose between screen space

Final Component Library (Partially Based on MB Design System)

Atoms (Basic building blocks)

App Panel

8 Text Styles

Headline

Ag

Secondary

Ag — **light** for monospaced numbers

Ag — **light** continous multiline text

Ag — **demi**

Tertiary

Ag — **demi** continuous text

Ag — **light** continuous text

mb / MbSans / tertiary / single_line

Ag — **demi**

Ag — **light**

15 Icons (+ Emojis)

Divider

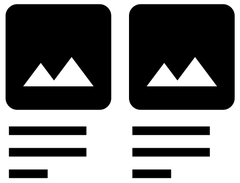
Image Skeleton

Layout Skeletons:

Vertical / Horizontal

Organisms (Derived from Atoms)

Horizontal List

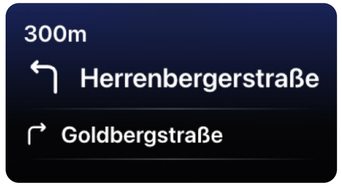


Listitem

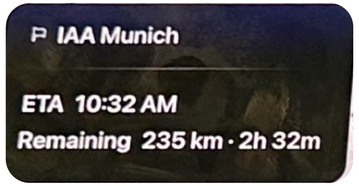
Headline...

Listitem with Image

Navigation



Additional Navigation



Core Formative Findings

Usability Heuristic Evaluation Exercise

4 **Designers** → were provided with → **Evaluation workbook + Scenario & Task** → find issues under → 10 **Usability Heuristics**

Visibility of System Status	Help users recognize & recover from error
Consistency & Standards	Aesthetic & Minimal Design
User Control & Freedom	Flexibility & efficiency of use
Recognition rather than recall	Error prevention
Help and Documentation	Match between system & real world

Severity Scale	Issues Identified	
0 (No problem)	1	
1 (Cosmetic)	6	
2 (Minor issue)	7 ✓	adjusted
3 (Major issue)	2 ✓	
4 (Catastrophe)	2 ✓	

Icon was used in the list with no information next to it whatsoever

System didn't acknowledge the user input

User Study

A/B Comparison (AI-Assembly vs Pre-defined)

(Priori + Sensitivity Analysis)

30 **Participants**

18 M, 12 F

Experienced 2 systems in randomized order

2 Preferences collected & entered into the system

2 news topics (Sports, Politics, Automotive)
UI preference (Minimal vs Rich)

Scenario: Drive from BB to MUC (IAA)

- Event -1: Briefing
- Event -2: Intermediate Stop for Breakfast (simulated driving)
  → Videos reviewed by 2 Experts for comparability
- Event -3: Taffic Jam

4 exprimental groups → Minimising Order Effects

Group	First Run	Second Run
1	Video 1 + System A	Video 2 + System B
2	Video 1 + System B	Video 2 + System A
3	Video 2 + System A	Video 1 + System B
4	Video 2 + System B	Video 1 + System A

After each event

- Value (UEQ+)
- Clarity (UEQ+)
- Visual Aesthetics (UEQ+)
- Mental Load (NASA TLX)
- Distraction (custom 7-point Likert)
- Open Ended Feedback

After each condition

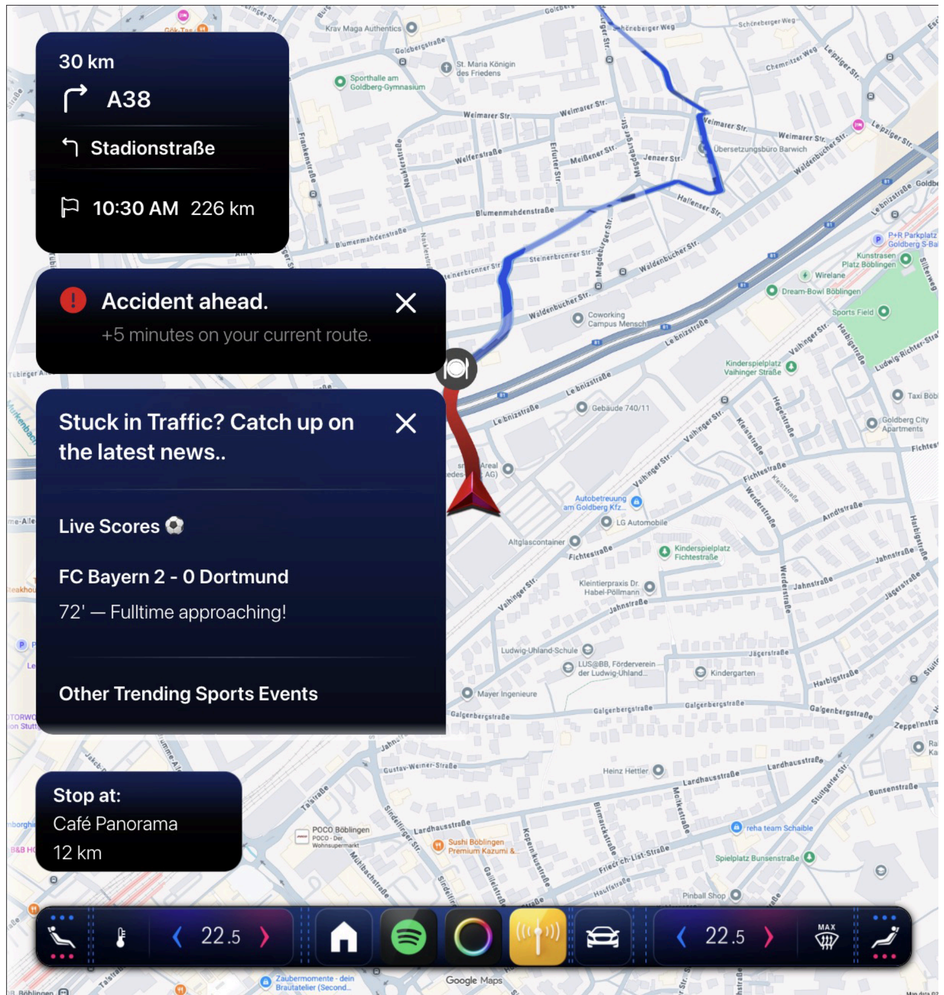
- Personalization (custom 7-point Likert)
- Adaptivity (custom 7-point Likert)
- UEQ-S

After experiment

- Distribution of 100 points between System A and B

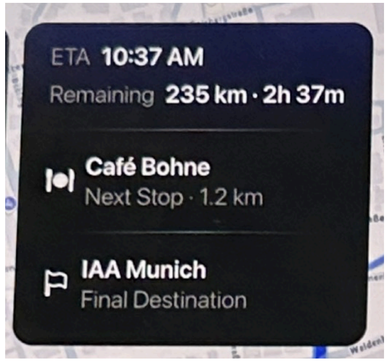
Example Outputs

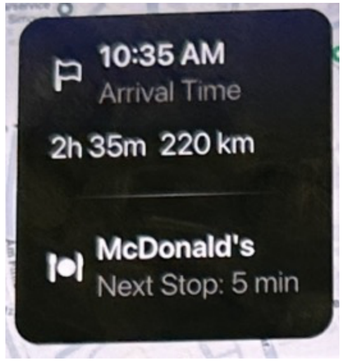
AI-assembled (Left), Pre-assembled (Right)

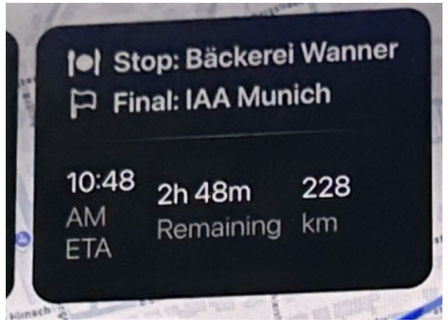


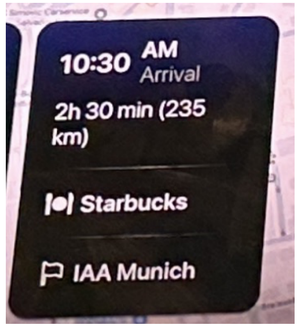
High Variance

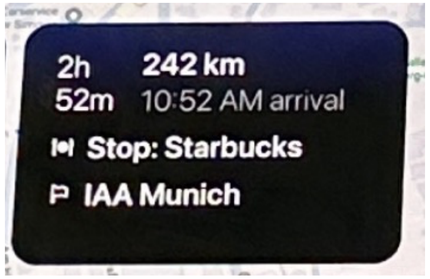
in the Organism-level component with the most freedom

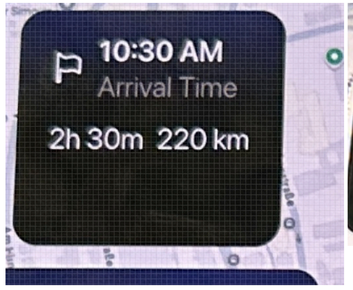


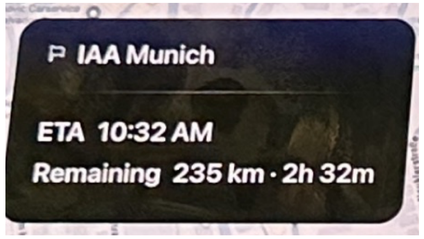


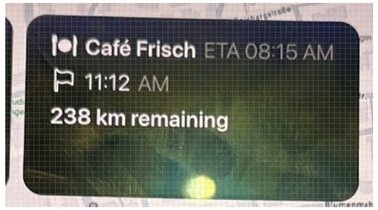


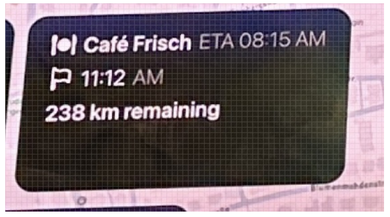












Results

Overall preference

Dividing 100 points between A/B

AI-assembled GUI

Ø 48.73

14 People (> 50 Points)
↳ 4 People (>70 Points)

Pre-assembled GUI

Ø 51.27

15 People (> 50 Points)
↳ 5 People (>70 Points)

Point Distribution p=.707

Individual Metrics

RQ 1	**Usability**	p=.514	**No sig. diff.**
	Clarity	***p =.089***	**H1**: 👍
	Value	p =.872	AI-assembled >= Pre-assembled
RQ 2	**Distraction**	p =.146	**No sig. diff.**
	Situational awareness	p =.310	**H2**: 👍
	Cognitive load	p =.235	AI-assembled >= Pre-assembled
RQ 3	**Personalization**	p =.909	**No sig. diff.**
	Contextual Adaptivity	p =.911	**H3**: 👎
			AI-assembled > Pre-assembled

Take Away

Performance

- AI performed on par with the baseline
- No improvement in adaptivity observed.....
    - Most likely due to very limited user data (one input - one output)
    - Repeated interactions may change outcomes

Safety Insight

- UI variation acceptable for supplementary content
- Variation in critical-components may introduce safety risks

Our Recommendation

Hybrid Strategy

Humans
critical components (e.g., navigation)

AI
Non-critical, supplementary components and areas

→ AI-based assembly = curator and builder constrained within safe boundaries.

→ Leverages Data = Personalized Experience

→ Potentially simplifies Development Processes

References

[1] GARZON, S. R.: Intelligent In-Car-Infotainment Systems: A Contextual Personalized Approach. In: 2012 Eighth International Conference on Intelligent Environments, 2012, S.315–318

[2] HARTWiCH, F. ; HOLLANDER, C. ; JOHANNMEYER, D. ; KREMS, J. F.: Improving Passenger Experience and Trust in Automated Vehicles Through User-Adaptive HMIs: “The More the Better” Does Not Apply to Everyone. In: Frontiers in Human Dynamics Volume 3 - 2021 (2021). http://dx.doi.org/10.3389/fhumd.2021.669030. – DOI 10.3389/fhumd.2021.669030. – ISSN 2673–2726

[3] WIEDNER, M. ; V NAVEENACHANDRAN, S. ; HALLGARTEN, P. ; MURUGABOOPATHY, S. ; FRAZZOLi, E. : CARSI II: A Context-Driven Intelligent User Interface. In: Adjunct Proceedings of the 16th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Association for Computing Machinery (AutomotiveUI ’24 Adjunct). – ISBN 9798400705205, 128–135

[4] SUNDAR, S. ; BOPP-BERTENBREiTER, V. ; ZiEGLER, D. ; KOSURU, R. ; KNECHT, C. ; PFLEGiNG, B. ; DiEDERiCHS, F. ; WiDLROiTHER, H. : PersonalAIzation - Exploring concepts and guidelines for AI-driven personalization of in-car HMIs in fully automated vehicles. In: PLANT, K. (Hrsg.) ; PRAETORiUS, G. (Hrsg.): Human Factors in Transportation Bd. 60. AHFE International (AHFE Open Access)

[5] REYES, G. : An Adaptive and Personalized In-Vehicle Human-Machine-Interface for an Improved User Experience. In: Companion Proceedings of the 25th International Conference on Intelligent User Interfaces. Association for Computing Machinery (IUI ’20 Companion). – ISBN 9781450375139, 35–36

[6] BÖLÜKBAŞi, E. ; IRAWATi, D. A. ; GERBER, M. A. ; RiENER, A. : Impact of Infotainment System Complexity on Driver Situation Awareness in Manual Vehicles. In: Adjunct Proceedings of the 16th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. Association for Computing Machinery (AutomotiveUI ’24 Adjunct). – ISBN 9798400705205, 312–315

[7] KRSTAČiĆ, R. ; ŽUŽiĆ, A. ; OREHOVAČKi, T. : Safety Aspects of In-Vehicle Infotainment Systems: A Systematic Literature Review from 2012 to 2023. In: Electronics 13 (2024), Nr. 13. http://dx.doi.org/10.3390/electronics13132563. – DOI 10.3390/electronics13132563. – ISSN 2079–9292