DESIGNING AUTONOMY FOR ALL

A designer's approach to the creation of more inclusive shared autonomous vehicles

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WELCOME.

This document provides details of design and other practice-based outputs resulting from the research outlined in the accompanying PhD thesis “Advancing Autonomy for All”. Please use this document to explore design concepts and research in further detail.

At the beginning of each section is a list of relevant inclusive design considerations as identified in the research. Not all of these considerations are addressed in the presented designs due to time and resource constraints. However, it is my hope that these considerations might prompt further thinking about the ways that these design concepts can be developed to further address exclusion.

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LOW-TECH ACCESS

The following section details concepts for alternative, non-smartphone means of accessing an SAV service including:

- **Simple public SAV call points**
- **Gesture-based SAV hailing**
- **SAV-specific personal devices for calling vehicles**

As SAV services may ultimately replace some more traditional transport services, it is essential that users of these 'legacy' services are able to easily make the transition. One key area of potential exclusion arises from the assumption that booking, planning and access to SAV services will be solely achieved through the use of smartphones and other personal digital devices. Many disabled people groups experience significant accessibility-related challenges using digital interfaces and other groups, such as older people, may have lower levels of digital proficiency and familiarity. This section explores concepts for alternative means of accessing SAV services that are less dependent on complex digital interactions.

INCLUSIVE DESIGN CONSIDERATIONS

Reliable and usable by multiple excluded groups including those with low digital literacy and disabilities influencing their use of interfaces

Provide alternative to inaccessible and unreliable smartphone use for accessing SAV on-demand and in public

Provide familiar and intuitive ways of accessing vehicle spontaneously

Reliable and usable by multiple excluded groups including those with low digital literacy and disabilities influencing their use of interfaces

Provide familiar and intuitive ways of accessing vehicle spontaneously at the roadside

SIMPLE PUBLIC INTERFACES

Some excluded passengers may not have access to a smartphone for calling an SAV when in public. Service access might be provided to these groups through the provision of public interfaces for booking and calling SAVs.

As a significant benefit of SAVs is the flexible, door-to-door service they provide, such public interfaces cannot be limited to specific locations or transport hubs, as is the case with for rail or bus services. Instead, public interfaces would need to be ubiquitous and easily locatable, reducing the need to walk to a particular location to begin a journey.

An obvious solution for public interfaces would be a simple button to summon the vehicle to its location. However, this concept presents potential for misuse and would generally only allow for private use of the service as matching ride-sharing journeys would not be possible without being able to input the desired destination. In some cases, sharing could be achieved with this type of interface if people at the same location with similar destinations decide to call a shared vehicle.

To ensure wider coverage (through reduced cost) and resistance to vandalism, public call points may need to reduce the number of complex features such as screens and keypads that might usually enable the input of destination information. Instead, public call points may be designed to provide a ‘lite’ SAV experience through the provision of controls which allow destinations to be selected from a pre-determined list, linked to a passengers’ travel card. These interfaces would require a means of validating the travel card (e.g. RFID reader) and a means of selecting from the pre-registered destinations (e.g. through numbered buttons or scanning different barcodes on the travel card according to the chosen destination).

The ability to save a list of common destinations and access them through simple interfaces could also allow for carer-led pre-programming of sequenced journeys, allowing independent use of the service for those with cognitive or learning disabilities for whom complex journey planning might be challenging.

To fulfil identified needs for pre-boarding journey information and interactions, public call points might indicate selected destination, ETA and allow a simple choice of shared/ non-shared vehicle. If provided, this information should be available in suitable visual, audio and/ or tactile modes. As additional controls and information are likely to increase the complexity and cost of these call points, the extent to which detailed information can be conveyed may be limited. Existing street-based interfaces such as the call button unit used for pedestrian crossings, give a reasonable idea of what might be achievable in this form factor with simple buttons, lights, audio, and tactile features (where a rotating tactile cone is provided beneath the unit).

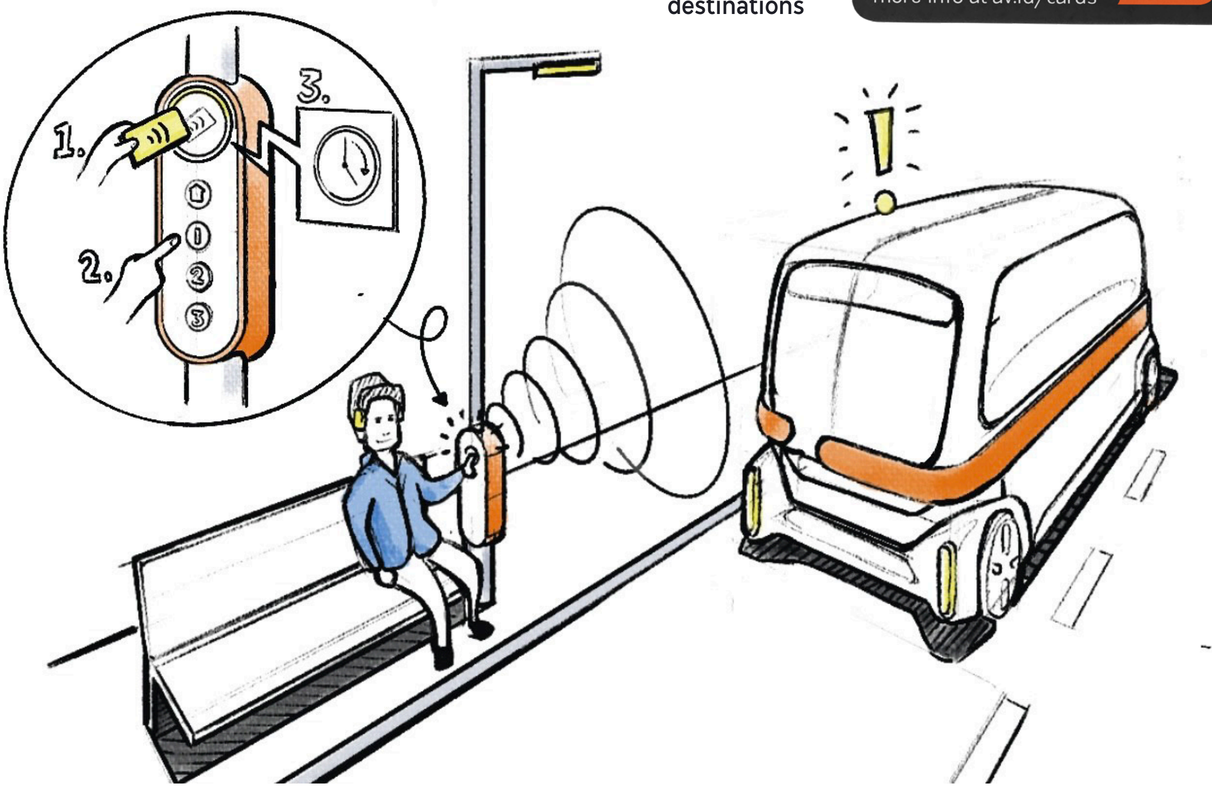
As well as using a travel card for interactions, public call points could also provide a failsafe option for smartphone users in the event of poor connectivity, allowing the use of destination codes that are saved in the app. For financially excluded passengers without access to a bank-account-linked SAV account, a public call point could be designed to scan destinations from pre-paid paper tickets purchased in advance from a public booking terminal. Alternatively, a pay-as-you-go travel card could be used, with payment and destinations loaded at public booking terminals.

Public call point and travel card concept design

The public call point concept illustrated below allows a passenger to tap their travel card (pictured on the right), select one of their preset destinations, and receive an indication of how long the vehicle will take to arrive (through an audio announcement or an LED countdown indicator).

This concept presents a very simple version of the public call point concept. To provide more sophisticated levels of choice and service use, additional functionality could be incorporated. Other potential additions to this concept could include a shared/ non-shared selection button, a payment indication (through a screen/ announcement), and an option to call a non-shared SAV and input the destination when the vehicle arrives.

Travelcard design with preset common destinations



Storyboard sketch of summoning SAV from a public call point

GESTURE-BASED SAV HAILING

For passengers who might have difficulty learning to use a new and unfamiliar mode of transport, and do not have access to mobile digital devices for SAV access, taxi-like gesture-based hailing might provide a familiar means of access.

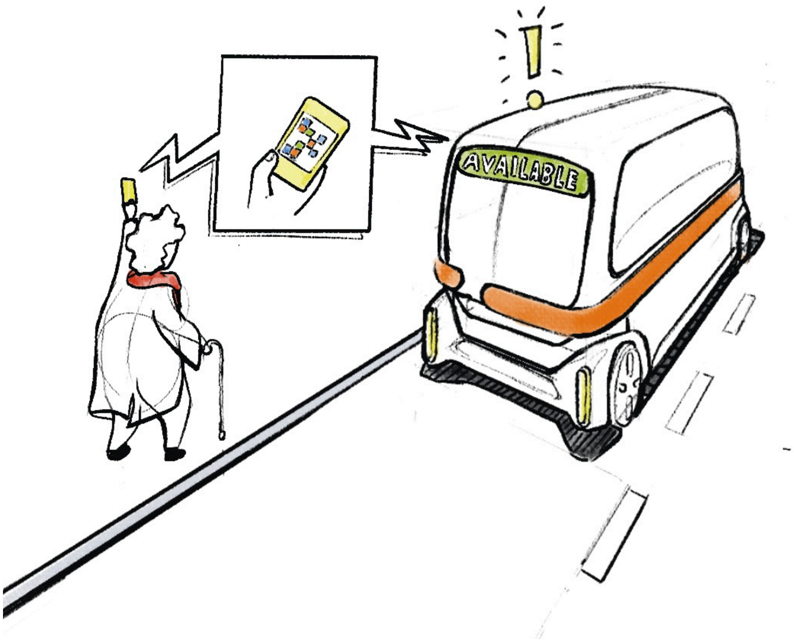
Gesture-based hailing was discussed as a potential alternative to smartphone-based service access by workshop participants with lower confidence and experience using digital devices. While not previously noted in literature regarding gesture-based SAV hailing, older workshop participants anticipated the potential for misuse of simple hand gestures by pranksters stopping vehicles without intending to board and suggested holding out a travel card to validate service access. Long range visual codes, similar to those used by Navilens (NUEVOS SISTEMAS TECNOLÓGICOS, S.L. (NEOSISTEC), n.d.), might allow the vehicle to validate the card from a distance. A concept design for this card is shown on the following page- note that the symbols are an aesthetic choice and wouldn't be necessary for recognition of the code.

For hailing a vehicle for a private journey, the passenger would need to know the vehicle is available- indicated through an external human machine interface (eHMI) on the vehicle- and indicate that they are a legitimate service user- communicated through the use of the travel card. The selection of their destination can be completed once onboard the vehicle- as there are no other passengers' routes to consider.

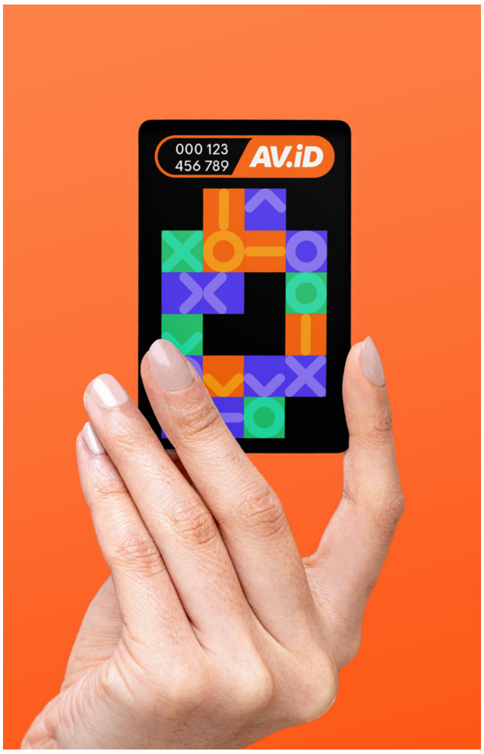
For shared SAV journeys, however, gesture-based hailing would present significant informational challenges, requiring prospective passengers to communicate their intended destination to the vehicle to ensure that a suitably efficient shared route is possible before the vehicle stops. A limited means of accessing SAVs in this way might be achievable to travel to a single pre-saved destination e.g. home. In these instances, a travel card with a unique visual code can be held out to a passing vehicle whose eHMI indicates it is carrying out a shared journey and has seats available. As the vehicle is shared, it would check that the hailer's home location coincides with its current route and stop if the journey is suitable.

To avoid multiple 'rejected' hailing attempts, shared SAV's eHMIs might also indicate their route to the hailer through an end destination, general direction (e.g. a compass point), or simple 'zones' that it is travelling through (demonstrated in the concept eHMI, and zone map on the following page). However, such complex comprehension and decision making in a short timeframe may be unachievable for many users and reliance on visual information at a distance would exclude many VI people, with audio alternatives inaudible from a distance.

Despite obvious challenges with designing for hailing, some SAV service contexts may benefit from this infrastructure-free method of access. Public call points may provide a more viable option than hailing in urban areas where such infrastructure can be widely implemented. However, less densely populated (e.g. rural) areas with fewer SAVs, may benefit from a hailing functionality allowing a few vehicles to patrol a local area before being hailed by a passenger. Such a system would allow a greater area to be served by door-to-door SAVs, while also providing non-digital means of access in areas which may be less likely to have strong network coverage.

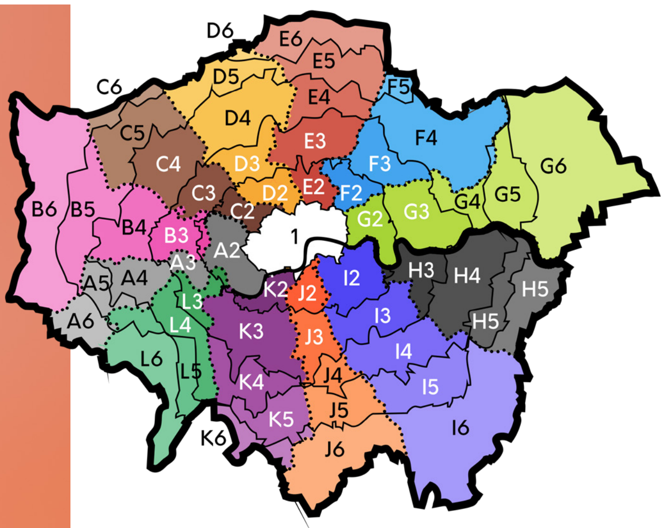


Storyboard sketch of SAV hailing with a travelcard



Travelcard with unique pattern for validation and hailing

eHMI design for hailing with availability, direction, zones, and destination shown



Map of a example SAV zone layout for London

Borough boundaries and TfL fare zones are used to a create familiar and memorable layout. Zone codes and colours can be used to indicate the route of shared journeys to prospective hailing passengers, allowing those with similar destinations to stop a passing vehicle.

SAV-SPECIFIC DEVICE

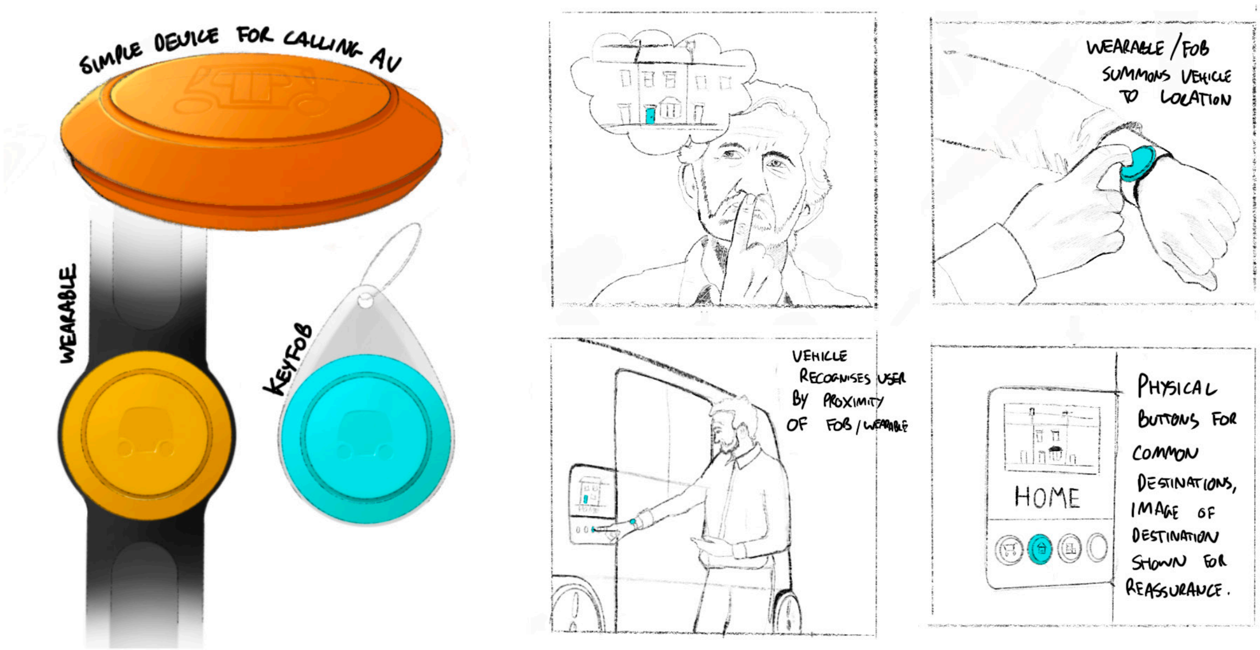
While a travel card and certain location-specific interfaces (e.g. on-vehicle and public) may provide a simplified "lite" version of the SAV service, they are still dependent on the presence of these interfaces in the prospective passenger's location and do not provide the same level of on-demand SAV access that smartphone apps might. To fill this gap, participants in research workshops discussed the use of simple, SAV-specific devices to call a vehicle to their location.

Such a device, illustrated in the concept design to the right could provide basic journey information through an e-paper display, and audio output, while buttons can be used to navigate a simple step-by-step booking process to access destinations from a list of pre-saved locations, and choose whether to share the vehicle. A simpler alternative device may only allow the user to call a vehicle to their location as illustrated in earlier ideation work shown on the right.

The table below demonstrates a how such a device might present a guided process to provide access to an on-demand SAV using a simple set of controls.

Information, options, and interactions to book SAV using simple SAV-specific device

Main text/ voice	Options	Actions
"Start journey"		Click screen
"Where are you going?"/ "Where would you like to go?"	Pre-set destination options- e.g. "Home", "Work". "Somewhere else" "Back"	Bumper buttons to navigate left and right through options Click screen to select
"Share your journey?"/ "Would you like to share your journey?" (Not asked if destination "Somewhere else")	"Shared" "Private" "Back"	Bumper buttons to navigate left and right through options Click screen to select
Journey details and price e.g. "Shared journey to home, £6.50"	"Confirm" "Back"	Bumper buttons to navigate left and right between options Click screen to select
Journey information e.g. "Shared journey to home, SAV arrival 10 minutes, arrive home 14:32"	"Cancel journey"	Click screen to repeat audio information Bumper buttons to navigate to cancel journey screen Click screen to select cancel journey
"Are you sure you want to cancel?"	"Yes"	Bumper buttons to navigate between options Click screen to cancel/ return to journey information screen



Initial sketches and storyboard for SAV-specific device

Concept SAV-specific device with simple button-based interactions, e-paper display and audio output.

SECURITY APP

The following section details concepts for app-based security features including:

- **Ways of allowing passengers to make informed journey choices to promote feelings of security.**
- **Features to improve security when walking to and from the SAV**

Being well informed about the journey and being able to make choices related to security, are key ways to improve the security of passengers using an SAV service. Security-related barriers and solutions were commonly discussed by women in inclusive design workshops, with a number of suggestions for how choices, and information might best be provided to SAV passengers. This section details designs for an SAV app that incorporates a selection of these features. The app presented here was demonstrated to women in the second set of focused workshops.

INCLUSIVE DESIGN CONSIDERATIONS

Collect personal information about passengers, allowing for individuals to choose shared SAV journeys that feel secure.

Calibrate security preferences to allow automatic recommendation of SAV journeys that feel secure.

Allow passengers to make choices about sharing a vehicle to improve sense of safety

Allow selection of safe and/or accessible drop off location

Less reliant on having smartphone in hand to reduce fear of theft

Ability to share location with service, friends, family to improve sense of security

Informing people about safety of the area

Allow monitoring of passenger location

Check that passenger has arrived safely at destination

Allow for feedback to inform safety of future journeys

SELECTING A SECURE JOURNEY

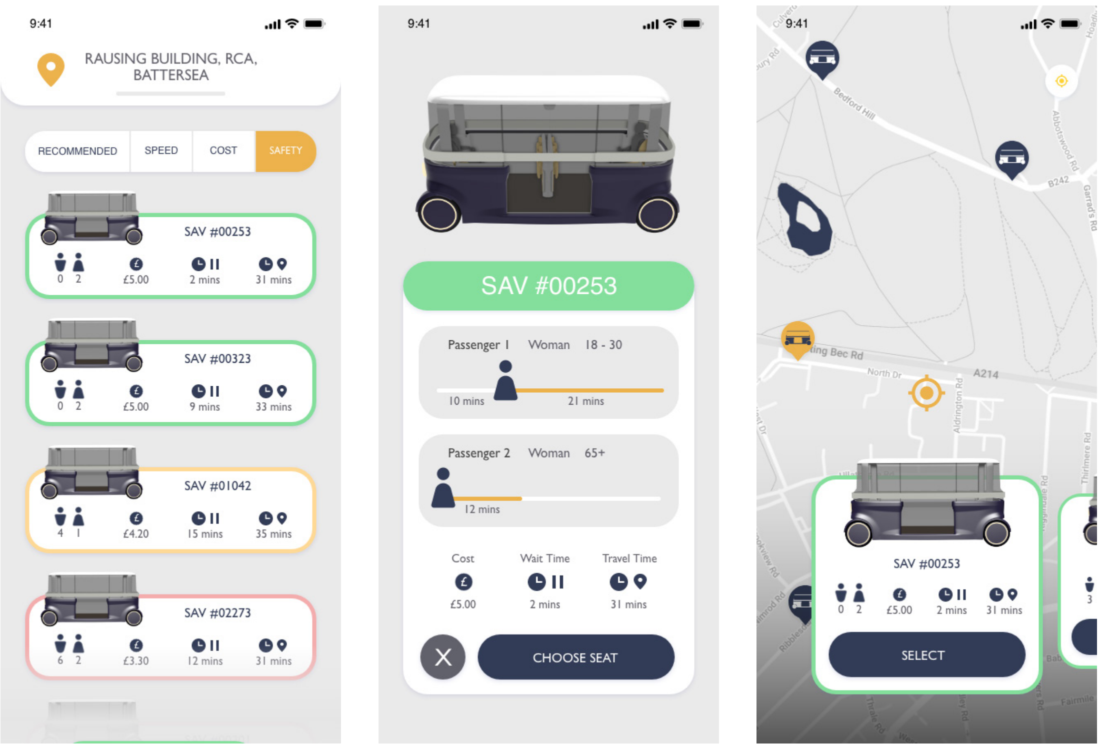
Providing information and choices about sharing before a passenger begins their journey was a common suggestion among workshop participants with information about other passengers' ages and genders seen as key to making safe choices.

Participants raised issues of privacy with sharing such personal data with other passengers, and challenges in making complex decisions based on individual passenger information. To avoid this, a concept app design was created with an anonymous recommendation system based on pre-calibrated security preferences.

SECURE JOURNEY SELECTION

When a journey is reserved, passengers are provided with a list of potential vehicles to choose from, showing key details about the number and gender of other passengers, journey timings, and cost. SAV options are given a colour code according to personal security preferences (red indicating a vehicle which might feel unsafe, amber indicating a vehicle that might feel safe in some conditions and green indicating a vehicle that will feel safe).

As some participants expressed that their



SAV app journey selection features. Vehicle options with security colour code (left), journey details with fellow passenger information (middle), option confirmation and vehicle location (right).

level of security concern is dependent on changing feelings and is not always a priority (e.g. if they are feeling more confident), this list can be sorted according to speed, cost, safety, and 'recommended' (suggesting a balanced combination of the other three priorities).

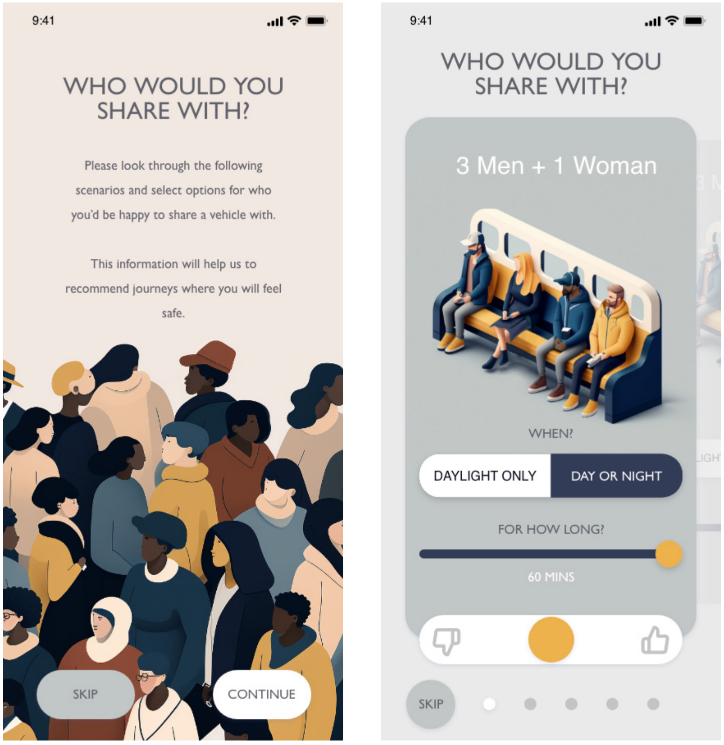
After selecting an initial option, a more detailed overview of the other passengers is provided, detailing the amount of time each passenger will be onboard for, when new passengers are joining the journey, passenger age ranges (to retain privacy of information while indicating a general age), and passenger genders.

Although workshop participants suggested the granular level of passenger information shown in the app interface, the reality of balancing this level of detail with other passengers' preferences indicates the need for a less intrusive alternative where such information (particularly sensitive information like gender) is not made public and - if provided - is only used to inform anonymous recommendations.

SECURITY PREFERENCE CALIBRATION

To ensure that the security recommendations provided by the app are tailored to the preferences of passengers, the app design features a calibration questionnaire, as suggested by W2P1.

This questionnaire (right) is designed to be completed upon registration with the service and may be periodically updated by passengers to ensure continued suitability of recommendations. Given the subjective nature of security preferences, the questionnaire feature has been designed to capture a sense of an individual passengers' security priorities by presenting them with sharing scenarios related to number and gender of fellow passengers and allowing them to adjust mitigating or aggravating factors (time of day and duration) before giving the complete scenario a score according to how



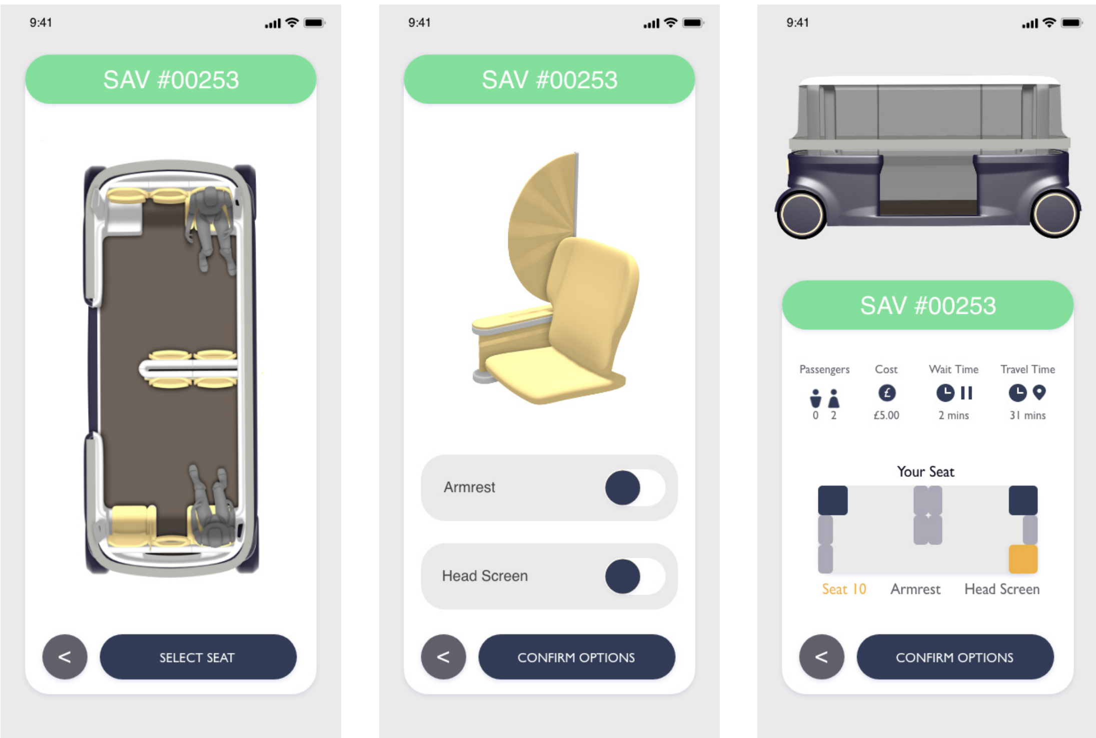
SAV app security calibration questionnaire.

safe it would make them feel.

As the combination of adjusting different factors and giving a score used in this initial concept could be overly complex, a simpler system could be used where passengers are simply required to give a rating or even give yes or no answer to whether they would share the vehicle in each scenario.

SECURE SEATING SELECTION

Seating position, the relative position of other passengers, and interior divisions are significant factors impacting the security of SAV passengers. To allow passengers to choose a secure seating position, the app (images below) was designed to allow a choice of seat while providing information about where other passengers are seated. The app design presented to workshop participants also allowed them to preselect the position of at-seat dividers, although this was considered to be unnecessary, with participants preferring dividers which can be manually positioned once seated.



SAV app seating selection features. Location of other passengers and seat selection (left), seat division choices (middle), option confirmation (right)

GETTING TO AND FROM THE VEHICLE SECURELY

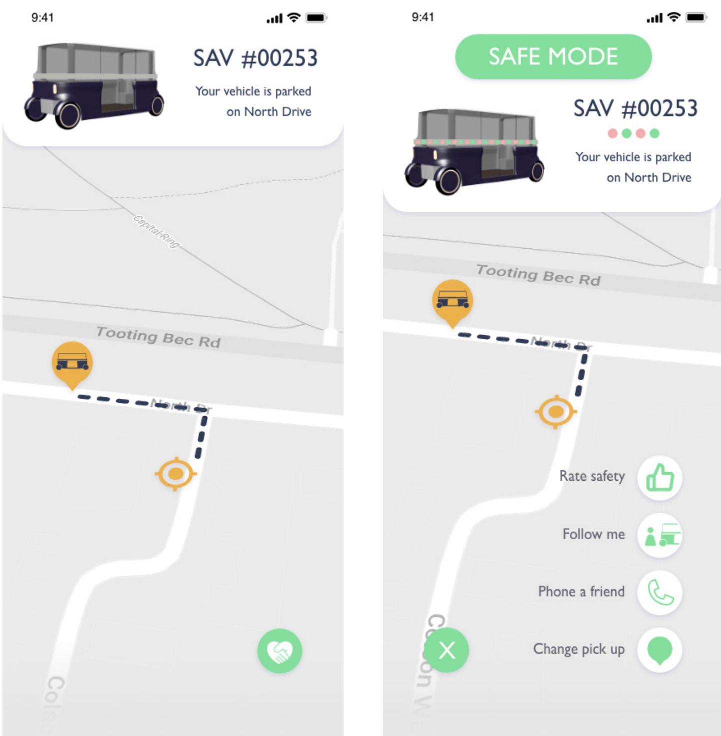
As well as booking and planning the journey, app interfaces may be used to improve security during the journey, particularly before and after leaving the vehicle. The app concept developed in response to workshop participants' security concerns incorporates a range of features intended to improve security which can be accessed when using the app to navigate to and from the SAV pick-up/ drop-off locations.

These features are:

Rate safety- allowing passengers to give feedback on how safe they feel in an area, informing the service's selection of future pick-up points.

Follow me- for journeys where the SAV cannot stop at the passengers' precise location, a follow me feature may allow the vehicle to drive alongside the passenger ensuring their safety until they arrive at a suitable boarding point. The slow driving speeds required for this feature would only be feasible in low-traffic areas and in journeys where no other passengers are onboard (to avoid delaying others).

Phone a friend- A commonly suggested strategy for improving feelings of security when walking was talking to a friend or family member on the phone. To allow for these calls to be made easily and quickly, this feature is incorporated into the app.



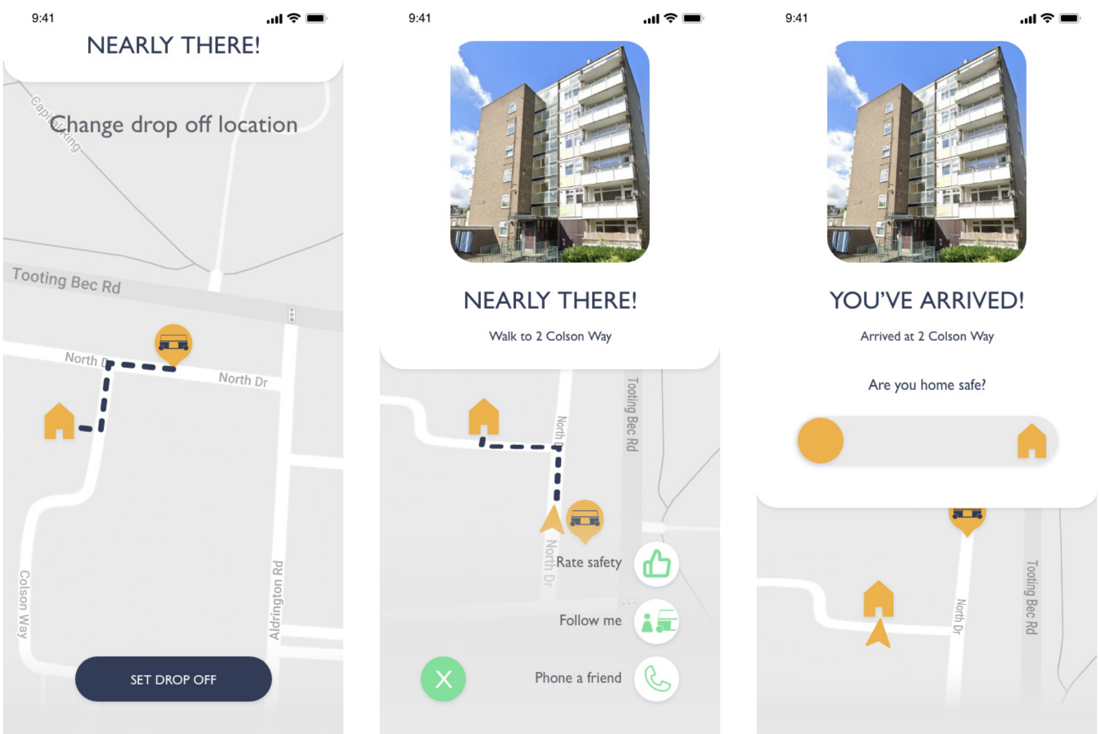
SAV app start-of-journey security features. Navigation to vehicle (left), safe mode options and vehicle information (right)

Change pick-up- If the suggested nearby pick up location is unsafe, passengers can use this feature to change it to an alternative nearby location.

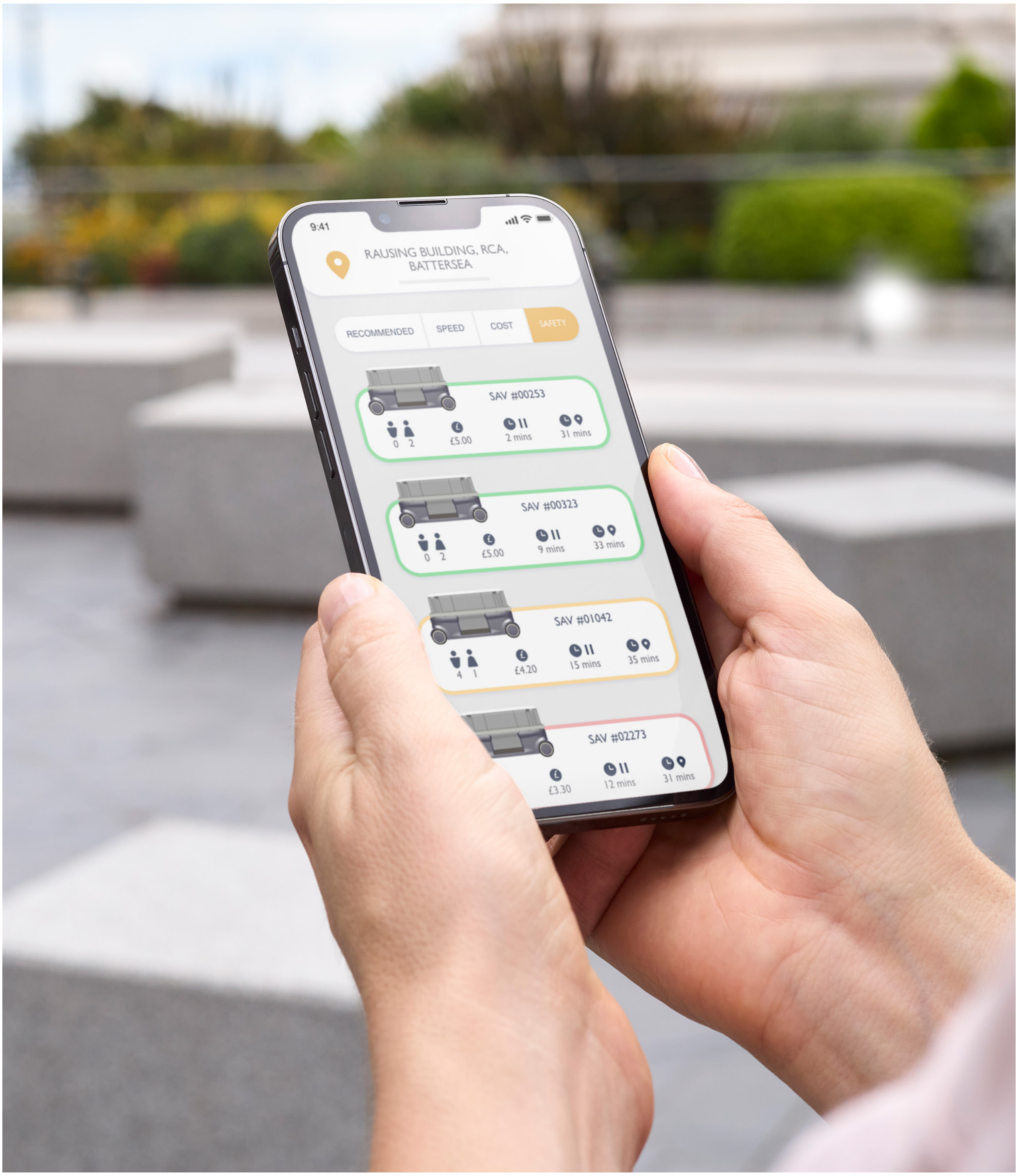
At the end of the journey, the app provides a similar set of features to manage the journey from the vehicle to the door. A notification prompts passengers that they are nearing the end of the journey and allows them to adjust the drop off point. Being able to adjust the drop off point was seen as helpful in reducing the distance to walk to the destination and ensuring the safety of the area you might be walking in.

A discussion around taxi use between two women in one of the second focused workshops indicated the importance of providing control over the drop off point to meet personal safety preferences. One discussed her preference to be dropped nearer to home with the taxi driver ensuring she enters the house safely, while the other mentioned how she provides a false address near to her home to retain her privacy. Similar privacy is likely to be required by some SAV passengers who wish to keep their home address secret from fellow passengers. For passengers who prefer a service that sees them to their door, a 'follow me' function was included in the app design. This feature is intended for scenarios where being dropped directly at the door isn't possible (e.g. because of reduced parking) but passengers want the service to ensure they are home safely.

In the absence of a driver to ensure passengers arrive home safely, the app also provides a 'home safe' feature where passengers confirm that they have arrived home safely. If confirmation is not received, this feature can be used to trigger notifications to friends, family, or the authorities.



SAV app end-of-journey security features. Changing drop-off location (left), safe mode options (middle), home safe confirmation (right)



SAV app mock-up showing journey selection screen.

VEHICLE INTERFACES

The following section details concepts for vehicle-based interfaces and features including:

- **Personal, at-seat interfaces with intuitive tactile controls**
- **External interfaces for communicating key information to passengers before they enter the vehicle**
- **Various inclusive information & interface functions suggested and discussed throughout the research**

Interfaces on exterior and inside the SAV are helpful in communicating journey information and allowing passengers to interact with the service. The provision of in-built interfaces is particularly true if a passenger does not have access to a personal device. As many barriers to excluded groups' use of transport relate to unavailability or inaccessibillity of information, the design of vehicle-based interfaces presents an opportunity to ensure the features and modality of such interfaces meet the needs of all passengers.


184
Booked
184
Tap to enter

INCLUSIVE DESIGN CONSIDERA

BOARDING

Provide familiar and intuitive ways of accessing vehicle spontaneously at the roadside

Validate entry to the vehicle to avoid misuse of service (e.g. tailgating) and reduce fear of sharing with unauthorised passengers

Allow simple communication of passenger needs to ensure they are met when journey is not pre-booked

Does not draw passengers' attention to operation of ramps or other boarding features to reduce stigma

Allow simple and accessible triggering of door opening reducing need for complex interactions

Allow simple and accessible triggering of ramp/ lift access for wheelchair users

Validate entry to the vehicle to avoid misuse of service (e.g. tailgating) and reduce fear of sharing with unauthorised passengers

Ensure visually impaired people are aware of layout of interior before moving inside the vehicle- particularly when interior layout may adapt

AT-SEAT INTERACTIONS

Provide simple, comfortable, and safe ways of entering journey information and access needs from inside the vehicle

Allow passengers to communicate access needs to the service ensuring access throughout journey

Allow people to choose to start vehicle once seated to

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reduce instability when moving onboard

Allow payment from comfort and safety of seat

Allow reporting of unclean or vandalised interior

Allow personal control of comfort features e.g. climate control and lighting

Allow passengers to share location with those they are travelling to, family etc.

Allow passengers to report negative passenger behaviours

Notify passenger of journey end

Allow selection of safe and/or accessible drop off location

Provide a viable alternative to a smartphone app for personal interactions with SAV for those who experience difficulties using smartphones

Reachable from wheelchair space

EMERGENCY INTERACTIONS

Provide intuitive means of controlling the vehicle if required in emergency scenarios

Provide easy means of communicating with service in emergencies

Clearly communicate information about service response to emergencies/ breakdowns e.g. arrival of replacement vehicle

Provide clear emergency exit navigation information to visually impaired people

Provide simple and discreet means of alerting service to dangerous passenger behaviour

INCLUSIVE DESIGN CONSIDERA

GENERAL/PUBLIC INFORMATION

Provide vehicle ETA information

Provide vehicle routing information

Provide vehicle service updates and alerts

Provide current location information for visually impaired people who cannot rely on view of outside

Reduce likelihood of passengers obstructing vehicle floor space to aid movement and navigation by disabled people

Non-audio formats for public alerts and notifications for hearing impaired people

Communicates exterior environment to visually impaired people when leaving the vehicle

Gives directions for onward journey

EXTERIOR INTERACTIONS

Provide intuitive, simple interactions on the exterior of the vehicle that are easy to use from the first attempt

Ensure key information about SAV (e.g. access and availability) is obvious to passengers before boarding

Allow location of a pre-booked SAV on the roadside by visually impaired people

Allow prompt location of a pre-booked SAV on the roadside to reduce feeling unsafe by being on the roadside

Allow passengers to pay for the service with simple and understandable interactions

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INTERFACE MODALITY AND ACCESSIBILITY

Provide intuitive, simple interactions inside the vehicle that are easy to use from the first attempt

Controls that do not require complex interactions or touchscreens to use

Provide a viable alternative to a smartphone app for personal interactions with SAV for those who experience difficulties using smartphones

Information made available in audio format

Information made available in easy to understand and read visual format

Automation of complex input of journey needs and preferences

Personal journey information is kept private from other passengers

Controls that are easy to locate for visually impaired people

EXTERIOR INTERFACES

EHMIs (display screens) can be added to SAV exteriors for various purposes, including identifying and locating the vehicle on the roadside.

Various means of visually identifying the vehicle to passengers were suggested throughout the workshops. Generally, participants were not comfortable with public displays of their personal information e.g. names and instead suggested more anonymous means of vehicle identification incorporating a unique code communicated privately to the passenger (e.g. through an app) and displayed on the vehicle.

A unique pattern of different coloured lights was discussed by women in the focused workshops as an easy means of both locating and identifying the SAV on the street, with a smartphone app allowing passengers to locate the vehicle matching the colour and pattern shown in the app. A concept design based on this suggestion was developed and presented to women in the second focused workshops. These simple colour patterns may allow identification by some passengers with low vision who may have difficulties distinguishing characters in text-based alternatives. However, the abstract nature of lighting colours and patterns make it challenging to communicate the unique lighting signature of a specific vehicle to prospective passengers. While this was achieved through a smartphone app in the initial concept, the use of an app for SAV identification may not be possible for all passengers due to previously discussed barriers related to smartphone use. Instead, visual means of vehicle

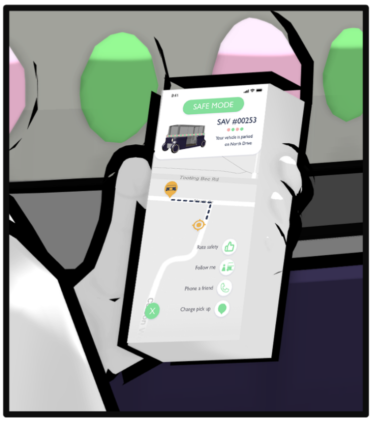
Storyboard sketches showing audio, visual, and haptic means of vehicle identification using smartphone apps and SAV-specific wearable device identification should be communicable to passengers through simple language that is mode-agnostic- i.e. it can be communicated through multiple means regardless of the level of technology access e.g. through phone calls, or in-person services. For this simple textual/ verbal communication, a vehicle number may be the most straightforward solution, with a lighting pattern provided as an additional means of identification.

For visually impaired passengers who are unable to distinguish coloured lighting patterns and written vehicle numbers, a non-visual means of identifying the vehicle should be provided. While the most obvious solution for this might be external audio announcements of the vehicle's number, VI participants often discussed subtler means of non-visual vehicle identification that do not require vehicle-based audio. These included a dedicated device such as a key fob or wearable that vibrates in proximity to the correct vehicle, and a smartphone app which uses the camera to identify a vehicle and give audio-based directions. As with visual identification, non-visual alternatives may also benefit from simple, memorable means of identifying the vehicle that can be communicated through multiple verbal or text based means without the need for a smartphone or dedicated device.

The concept inclusive SAV design incorporates visual identification features displayed through external displays. These features include a number which provides a familiar and memorable identifier and a colour code that is more easily visible from a distance and by some visually impaired passengers. As SAV services will incorporate a degree of connectivity between vehicles, these unique identifiers are only required to distinguish between a relatively small number of vehicles within the immediate vicinity of the passenger, rather than differentiating every vehicle in the fleet. Because of this, simple numbers and colour codes can be used to aid memorability and ease of communicating the identifiers to passengers through multiple booking and planning modes.

For non-visual identification, inclusive SAVs may incorporate a unique sound that indicates their general location when stopped at the roadside. To identify a specific vehi-

Storyboard sketches showing colour pattern matching for anonymous vehicle identification using SAV app



cle, external audio announcements are used to periodically repeat the vehicle's unique number. As identification of specific vehicles is only relevant in the case of pre-booked on-demand or reservation-based SAVs, these announcements may only sound when a visually impaired person is using the service to avoid creating unnecessary noise.

As the general location of an SAV may be difficult for visually impaired (VI) people to navigate to, further consideration may be given to the use of personal devices to recognise the vehicle and provide more detailed directions to its location.

The EHMIs on the side of the concept vehicle can also be used to show simple colours, graphics and animations, to indicate actions such as door opening and closure (shown on the right). For VI people, audio indication might also be used to indicate this.

SAV exterior with front eHMI showing simple number, colour, and symbol based means of identification.

SAV exterior with side eHMI showing door opening indicators.

INTERIOR INTERFACES

For some more personalised or private inforation or interactions interfaces may be provided at passengers' seats. The following section discusses the design of a concept inclusive at-seat interface.

The proposed inclusive SAV personal interface design incorporates several different input modes. For controlling the interface, the primary mode of control is through physical means- a directional joystick with left, right, forward, backward directions, and a large button for selection. These physical controls were selected to reduce the need for strength, dexterity, or accuracy in interactions, while being operable with a closed fist (as recommended by Klinich et al. (2022)). Similar controls are commonly selected for applications in products designed for disabled people such as accessible gaming controllers and powered wheelchairs. As well as reducing the physical demands of interaction, this interface mode also provides a degree of flexibility in the types of control it can be used to operate e.g. left/right can be used to navigate the interface or adjust elements such as temperature controls. The use of these interactions and optimisation of the graphic user interface (GUI) for their use, also creates the potential for other directional and selection based input modes including touch-free gestures and simple voice commands, as well as the potential for the connection and use of simple peripheral devices to interact with the vehicle interfaces.

At-seat interface with travelcard icon prompting passengers to tap their card to show specific journey details etc.

While a more inclusive standard interaction mode is beneficial, inclusive input devices may sometimes incorporate modularity to allow disabled people to tailor interactions to their abilities, an approach used by Microsoft for their Xbox Adaptive Controller (Microsoft, 2024). Wearables and chairables (devices that can be mounted to a wheelchair) that connect to a smartphone have also been suggested to improve the accessibility of these devices for wheelchair users (Carrington et al., 2014). Similar, dedicated devices that connect to the SAV could allow use for those who remain unable to use or reach the provided means of input. For example, a Bluetooth compatible joystick control attached to the armrest of a wheelchair could be paired with the SAV, allowing a wheelchair user to control a personal at-seat interface even if the vehicles built-in controls are out of reach.

Given the degree of adaptability required in the interior space, any personal interface must be positioned in a way that is reachable and visible in all seating configurations.

Interfaces may be located in a fixed position that is accessible from all seating configurations (e.g. on a vehicle side wall) or positioned on a component of the seat that can, itself, be manipulated to the correct position (e.g. built into a folding armrest). As the second of these options creates a degree of complexity related to the addition of electronic equipment to moving components, the concept inclusive SAV has sought to locate interfaces in fixed positions where possible. Interfaces for the reversible seating and one folding seat are fixed to the vehicle wall and dividers with a simple swivel movement to rotate the interface to the correct position. Only one of the folding seats in the wheelchair space requires the interface to be fixed to a folding armrest to allow the seat to completely fold away for easier wheelchair manoeuvring.

To ensure the controls for the interface are reachable from the wheelchair space the folding armrest may be further developed to swing towards the wheelchair user. For wheelchair users who might still be unable to reach or use the controls, a "chairable" device could be used to control the interface.

It is essential for the interface to provide both audio and visual output modes for information. For the design of this interface, a screen and audio equivalents are provided with the latter made available through discreet headrest-mounted speakers or bluetooth headphone pairing.

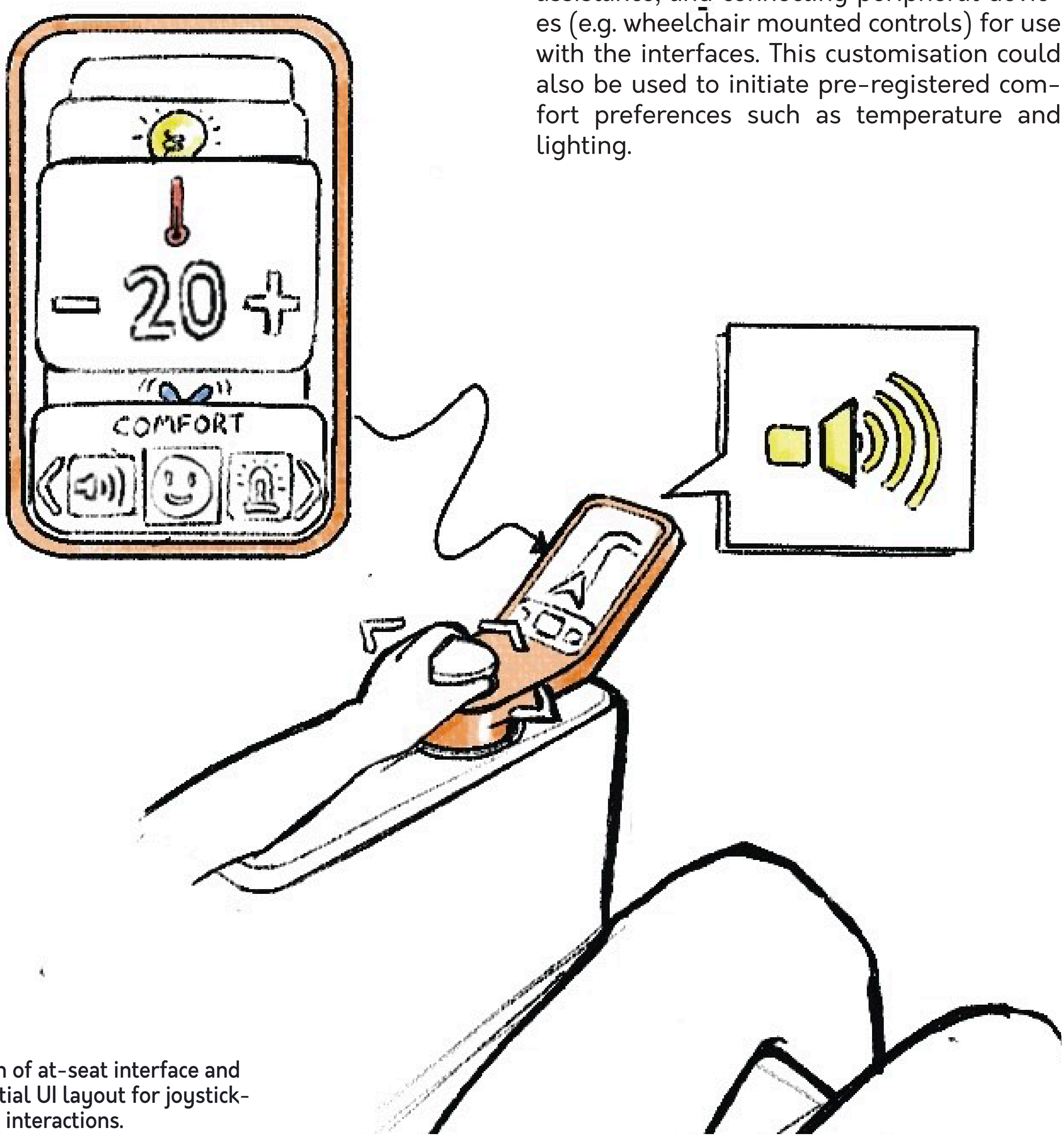
As information is often primarily displayed through a screen, visually impaired people may use screen readers such as Apple's Voiceover which read out the content of the screen as they move their fingers over it. While these features do provide basic usability of these devices to visually impaired people, the amount of information on the screen and the need to navigate around the screen to locate the appropriate options can be overwhelming (Kuber et al., 2012).

As a more specialised interface, with fewer features than a smartphone, SAV-based interfaces can be designed to order information in a way that is more optimised for audio. To ensure that the interface is easy to navigate in an audio format, a user interface has been proposed that utilises a simple menu system with multiple levels.

At-seat interface locations by front/rear seating.

The highest level of the menu system would utilise broad categories for example comfort, interface settings, and journey information, this menu can be navigated by moving the joystick left and right. Moving the joystick forwards navigates users into a submenu with more granular categories e.g. for comfort, lighting and temperature controls are provided. Each of these options shows a screen with several widgets arranged vertically which can again be navigated by moving the joystick forwards or backwards. Each widget can be controlled with left and right movements of the joystick and by pushing the joystick down to select where necessary.

As disability and other excluding factors can impact each passengers' requirements for input and output modes and other interface-related preferences, a smart travel card or app could be used to indicate these preferences to the vehicle, allowing the interface to adapt accordingly. The most significant adaptations are likely to be adjusting the size and contrast of graphic elements on the screen, initiating audio output modes, initiating voice assistance, and connecting peripheral devices (e.g. wheelchair mounted controls) for use with the interfaces. This customisation could also be used to initiate pre-registered comfort preferences such as temperature and lighting.



Sketch of at-seat interface and potential UI layout for joystick-based interactions.

At-seat interface location for reversible seat. Interface can be swivelled to face forwards or backwards.

At-seat interface location for fixed folding seat.
Interface attached to folding armrest.

INTERIOR INTERFACES: INCLUSIVE FUNCTIONS

The at-seat interface design was mostly explored in the context of inclusive interaction and information modes, and the design of specific functions was outside of the scope of the project. However, as participants made valuable suggestions about such features, a selection of potential functions are described below in the context of the inclusive design consideration they address.

Allow people to choose to start vehicle once seated to reduce instability when moving onboard: Passengers press single button to start the journey once seated or, in the case of spontaneous SAV access, passengers input journey information and make payment to initiate journey.

Allow payment from comfort and safety of seat: Passengers tap travel card, phone, dedicated device, or bank card to make payment when journeys are not booked in advance.

Allow reporting of unclean or vandalised interior: Passengers can report interior damage, uncleanliness etc. through the interface, with a simple guided questionnaire to understand the severity and type of issue.

Allow passengers to report negative passenger behaviours: In non-emergency scenarios, passengers can report negative behaviour of fellow passengers through the at seat interface. Footage from the vehicle interior CCTV cameras can be used to validate reports and trigger appropriate action against poorly behaved passengers. (For emergency reporting see following section)

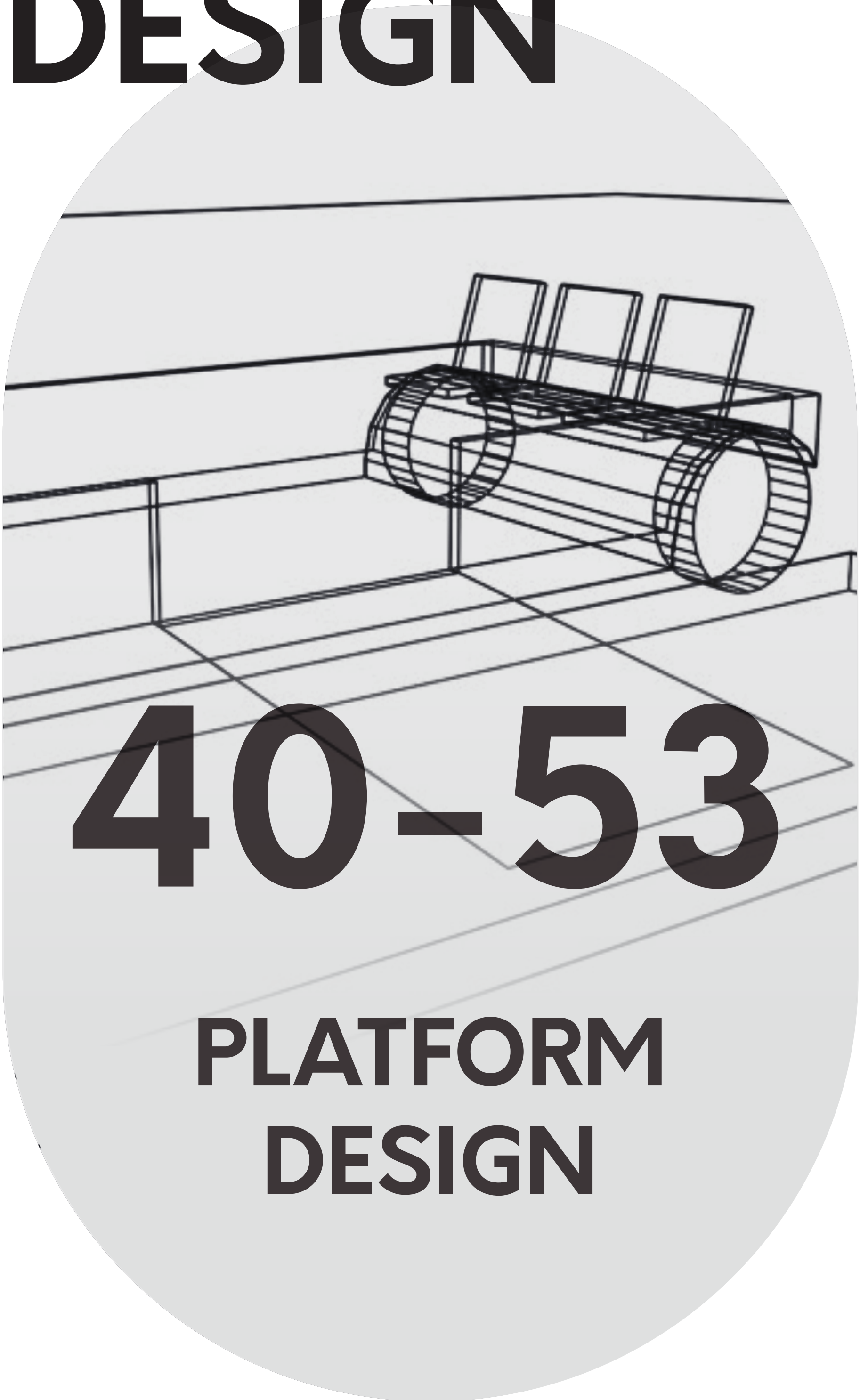
Allow personal control of comfort features e.g. climate control and lighting: Passengers can adjust comfort features at their own seat e.g. lighting, air conditioning etc. Although for many these features are solely for comfort, for some disabled people they can have more significant impacts e.g. cold vehicles compounding pain symptoms.

Allow passengers to share location with those they are travelling to, family etc.: Passengers may select a friend or family member, linked to their account with whom to share their journey. This was suggested for improving security, but also for general communication and convenience e.g. P7's family knowing his ETA.

Allow selection of safe and/or accessible drop off location: Similar to the drop off point selection in the app design discussed above, onboard interfaces could also allow for this with a simple map of the general destination area showing all potential drop-off points which can be navigated and selected with the joystick and button controls.

Notify passenger of journey end: Vibrations, audio announcements through seat-located speakers, and visual notifications on the screen could all alert passengers of the end of the journey. Provision of vibrotactile alerts could be particularly helpful for hearing impaired passengers who have difficulties hearing announcements when using public transport modes and experience the additional burden of having to remain alert to access this information through digital displays. As the vehicle will know the destination of the passenger in any seat, a simple vibration can indicate when they need to depart, something that is not possible in existing public transport modes.

VEHICLE DESIGN



40-53

PLATFORM DESIGN

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80–85
EXTERIOR
DESIGN

PLATFORM DESIGN

The following section details concepts and tools for more inclusive SAV platform design and engineering including:

- Decisions and inclusive design considerations regarding key parameters including wheelsize, floor height, and interior space.
- A kneeling suspension system to reduce step-in height and wheelchair ramp angles when boarding.
- A parametric design tool to demonstrate the impact of design decisions on vehicle floor height

The design of the platform on which an SAV is based dictates many aspects of the use of the vehicle and can have many knock-on effects on the level of inclusion that might be achievable through subsequent vehicle design decisions. The following section details the development of a concept SAV platform used as the basis for further design activity throughout the project. As detailed in the accompanying thesis, this work was supported by discussions with experts in vehicle packaging engineering (referred to as E1 and E2) to ensure the concepts retain a degree of feasibility. Future work should seek to validate the feasibility of the platform design concepts that follow.

INCLUSIVE DESIGN CONSIDERATIONS

Reduce vehicle step-in height to make entry easier for disabled people

Reduce ramp steepness/ allow for level boarding to ensure efficient and independent entry for wheelchair users

Reduce protrusions into the interior space to allow unobstructed movement and navigation

COMMON SAV PLATFORM CHARACTERISTICS

As explained in Chapter 5 of the accompanying PhD thesis, the vehicle developed during this project was designed with the approximate exterior dimensions of L=4800mm, W=2100mm, H=2800mm based on a benchmark of similar shuttle-type vehicles. Before further considering the inclusive design implications of vehicle platform design certain characteristics and features of existing SAVs were identified to ensure that the inclusive SAV concept is developed in line with expectations for such a vehicle.

Space efficiency - Using as much of the vehicle footprint as possible to maximise passenger occupancy. This is often accomplished through the placement of wheels at the corners of the vehicle - reducing wheelhouse encroachment into interior space - and the addition of seating above these wheelhouses. This tends to result in a "one-box" exterior design for SAV shuttles which allows for seating at the front and back and removes the potential for more traditional vehicle designs with a bonnet at the front.

Four wheel independent steering (4WIS) - The application of independent steering control of each wheel. This enables greater manoeuvrability through novel movements including steering out of phase - front and rear wheels turning in opposite directions to create tighter turning circles - and in phase - front and rear wheels turning and remaining parallel (TUMCREATE, n.d.). These systems impact the available interior space due to larger wheelhouses required.

OPTIMISING AN SAV PLATFORM FOR INCLUSION

Chapter 4 of the accompanying thesis describes how visually impaired people, wheelchair users, and other mobility impaired people can all experience difficulties with boarding vehicles due to the size of the step into the vehicle, and the steepness of vehicle ramps.

Currently, the UK's public service vehicles accessibility regulations (PSVAR) dictate that ramps on such vehicles should meet the ground at an angle of no more than 7 degrees (The Public Service Vehicles Accessibility Regulations, 2000a). This angle, however, can be too challenging for some wheelchair users to board independently- as evidenced by a research workshop participant (WU1), who was unable to independently board the SAV mock-up with a ramp constructed to PSVAR standards.

Given the likely absence of transport staff in SAV services, it is necessary for inclusive SAVs to provide independent entry. To ensure the ramp can be used independently by wheelchair users, the inclusive SAV concept seeks to incorporate a ramp with maximum incline of 1:12 (or ~ 4.8 degrees as suggested in inclusive SAV guidance (Klinich et al., 2022)), similar to those required in the design of buildings (The Building Regulations, 2010).

A gentler ramp angle requires a longer ramp for a given vehicle floor height requiring a low vehicle floor to allow for a ramp that is short enough to be stowed onboard the vehicle and deployed onto pavements. As both ramp angle and step-in height can be optimised through minimising SAV floor height, this was determined to be an essential aim for an inclusive SAV package. During discussions with vehicle packing experts E1 suggested the platform should seek to reduce two dimensions to lower the vehicle floor height, namely:

Ground clearance (GC) - the distance between the road surface and the underside of the vehicle, determined by the area and terrain in which the vehicle might operate.

Sill depth (SD) - the thickness of structural components of the vehicle platform which dictate the distance between the vehicle floor and the vehicle underside. In electric vehicle powertrains, this is often determined by the height of batteries which are packaged beneath the floor but it may also be dictated by the structural requirements of the vehicle chassis.

E1 suggested that packaging the vehicle batteries under or behind seating at either end of the SAV could reduce the sill depth. This approach is used in Holon's Mover SAV which achieves a low step-in height of 270mm (beep, 2024). Other SAV designs with under-floor batteries can have significantly higher step-in heights e.g. Steel E-motive's SEM1 at a height of 392mm (170mm GC + 212mm SD). As it is challenging to find further public sources for detailed SAV dimensions, the Holon Mover's step-in height (130mm GC + 140mm SD, estimated based on available images) has been used as a benchmark for the inclusive SAV concept vehicle.

As noted by E1, innovations in material and the design of body structures might serve to reduce the sill depth further as SAV technology matures. Furthermore, innovations in battery technology such as Ionetic's 80mm high Arc battery platform may allow for a reduction in floor height alongside the space efficient packaging of batteries ("Arc Platform," n.d.).

In addition to directly reducing the sill depth or ground clearance of the SAV, other dimensions may also impact the overall step-in height. If an SAV is to make efficient use of the entire vehicle footprint for passenger occupancy, it is necessary to incorporate seating at either end of the vehicle, above the vehicle's wheels. The size of the wheels, clearance for suspension components and travel, and the thickness of the wheelhouse material (usually a thin, single layer of metal in the range 0.5-2mm (Steel E-Motive, 2023)), all dictate the height of the wheelhouses. The difference in height between the top of the wheelhouses and the floor surface, in turn, impacts the seat pan height which must itself meet ergonomic requirements for the comfort of a wide range of passengers. The factors influencing floor height are illustrated below.

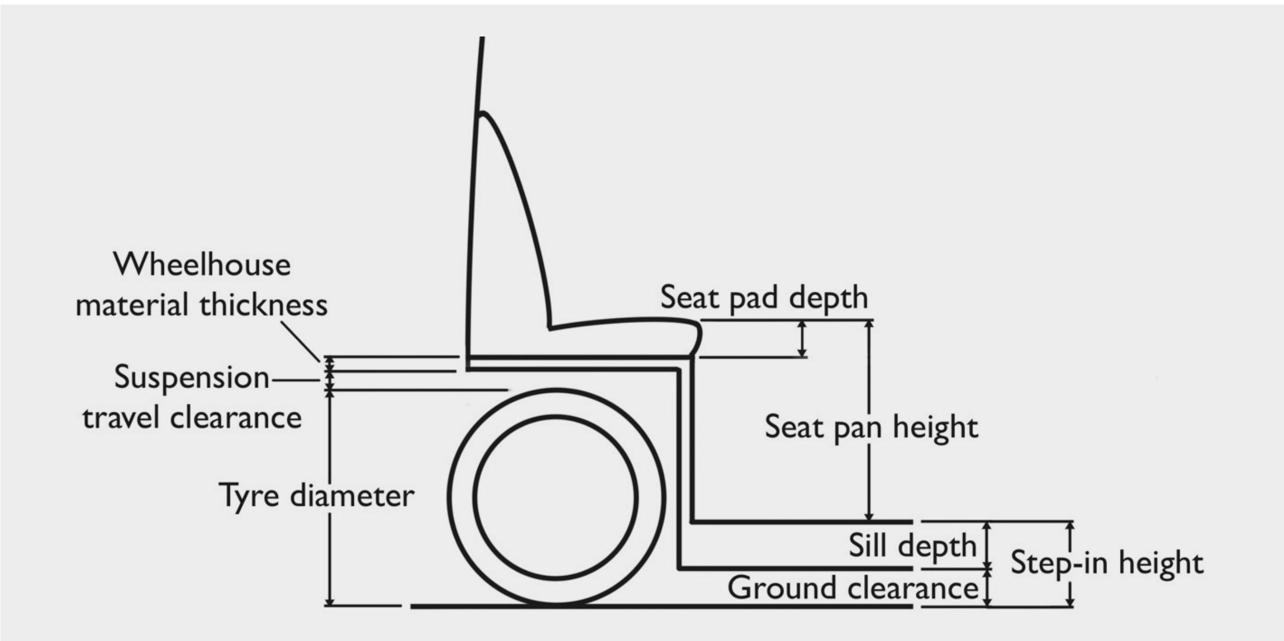
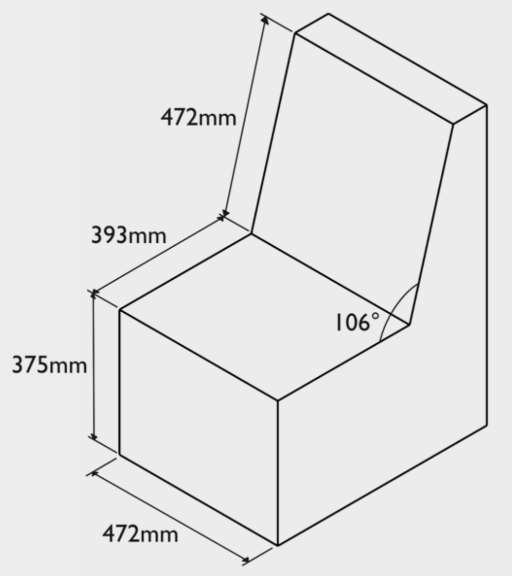


Diagram of dimensions which influence SAV step-in height

SEATING DIMENSIONS

As seating design can have a significant an impact on key inclusive platform design decisions, a seating envelope was defined according to anthropometric data and literature describing recommendations and best practice. These dimensions are shown in the diagram and table below.



Dimension	Value	Reason for selection
Seat pan height	375mm	5th%ile South African male popliteal height +15mm shoe sole thickness (Vink, 2016)
Seat pan width	472mm	99th%ile intl. hip breadth- DINED (Molenbroek, 2018)
Seat pan length	393mm	5th%ile Chilean child buttock-popliteal depth DINED (Molenbroek, 2018), suggested by Vink (2016)
Seat back height	472mm	Sitting shoulder height 532mm with 60mm subtracted for free shoulder space, suggested by Vink (2016)
Seat back angle	106°	Comfortable upright position suggested by Vink (2016)

Diagram and table of seating dimensions.

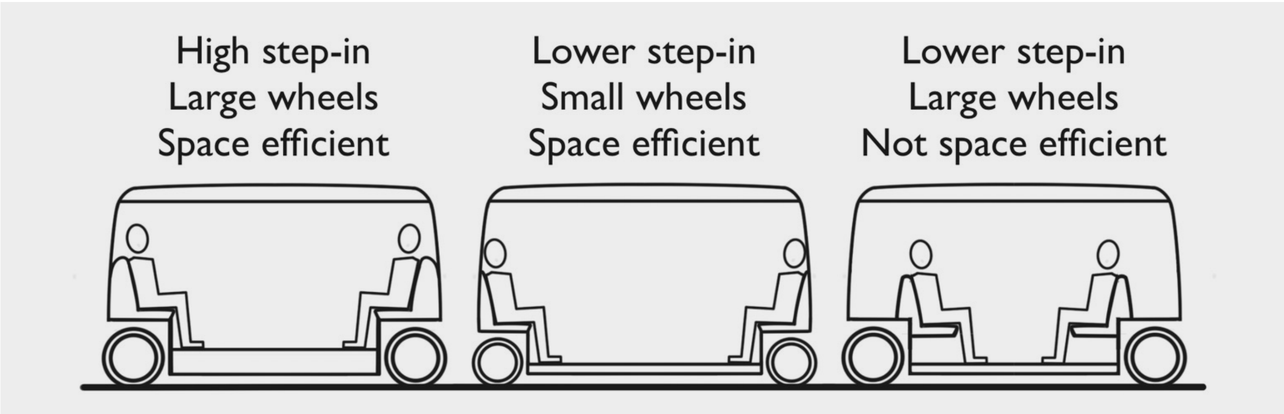
WHEEL SIZE

Both vehicle packaging experts interviewed during the process discussed the impact of wheel size on the vehicle package and the role that automotive designers often play in the decision making process. Somewhat surprisingly for such a functional element of a vehicle, both experts suggested that wheel size is often dictated by the aesthetic appeal, determined by designers to improve the overall proportions of the vehicle. In fact, aesthetic appeal is even detailed as a justification for a larger wheel size in the SAV packaging-focused Steel E-Motive project (Steel E-Motive, 2023).

While visual appeal is invariably important, the potential impact of larger wheels in raising the floor height of the vehicle has significant implications on the accessibility of an SAV. The competing interests of vehicle designers- prioritising larger wheels, SAV service providers- requiring efficient use of space to maximise passenger occupancy, and the needs of disabled people- requiring a low floor height- creates a predicament in the design of inclusive SAV packaging, where any two of these requirements might more easily be met to the exclusion of the third (shown in the illustration on the right).

Some SAV designs overcome this challenge with the addition of interior steps allowing access to seats above the wheelhouses while retaining a section of low floor for wheelchair access. This approach, however, presents its own challenges for disabled people including visually and mobility impaired people who have difficulties navigating vehicle interiors with steps. As such, it was decided that the SAV concept developed during this project would seek to minimise wheel size, potentially sacrificing a degree of aesthetic appeal in favour of more pragmatic and inclusive priorities.

A minimum wheel size suggested by E1 for use in a vehicle such as an SAV was 650mm diameter and E2 suggested 680mm. Even with these minimum estimates, a requirement for seating above the wheels can still raise the floor higher than is required by ground clearance and sill depth. The table below demonstrates a minimum estimated step-in height of 380mm based on E1's wheel size and a seat pan height to accommodate a significant proportion of passenger dimensions. Such a high floor height would require a 3m long ramp (1:12 gradient) to board from a kerb height, a length which would be impractical to stow onboard the vehicle and unsuitable to be deployed in many locations.



Illustrations of SAV platform trade-offs

Key platform dimensions for an SAV with 650mm wheel diameter

Dimension	Value	Justification/ calculation
Seat pan height from ground (a)	755mm	650mm (wheel diameter) + 100mm (estimated suspension jounce) + 5mm (wheelhouse thickness)
Seat pan height from vehicle floor (b)	375mm	375mm (5%ile South African popliteal height + 15mm shoe sole thickness, (Vink, 2016))
Floor height from ground (c)	380mm	a-b
Ground clearance (d)	235mm	c-140mm (sill depth)
1:12 ramp length to 125mm kerb	3000mm	(c-125)x12

KNEELING SUSPENSION SYSTEM

To further reduce the distance between a kerb and the vehicle floor, vehicle packaging expert, E1 (as well as several workshop participants) suggested the use of a kneeling air suspension system which could reduce the ground clearance when the vehicle is stopped. Such systems are already commonplace in buses and existing autonomous vehicle designs such as Cruise's WAV (Cruise LLC, 2024).

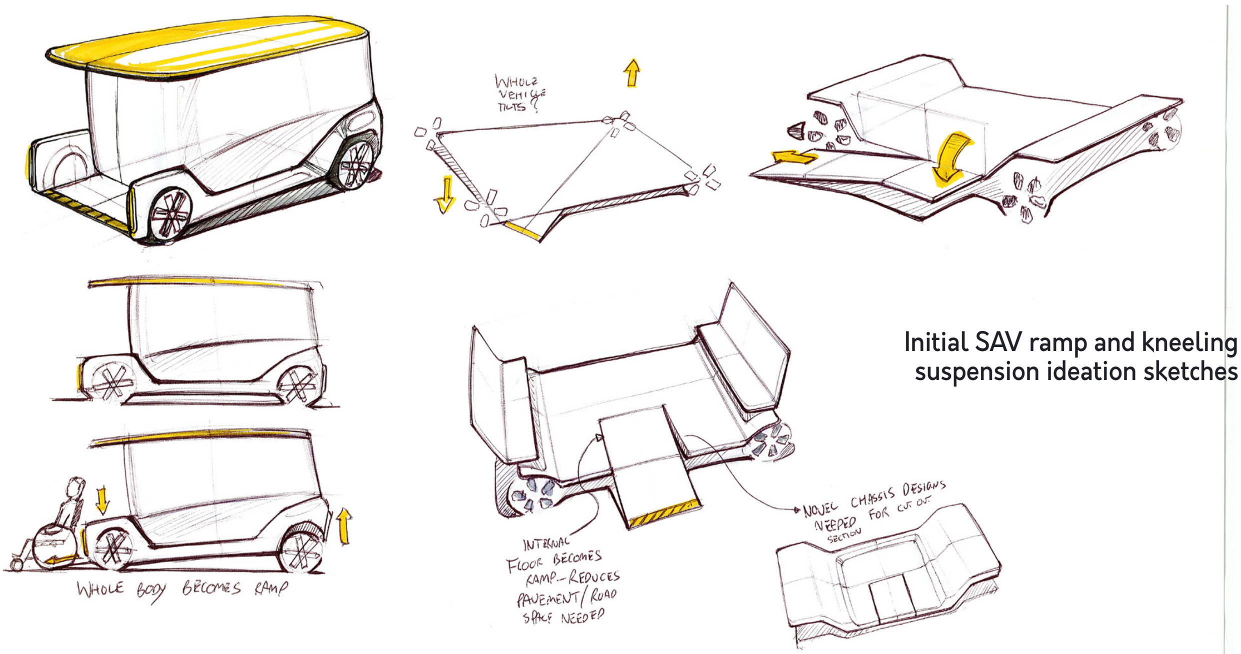
Initial ideation explored several concepts for kneeling suspension systems and ramp configurations (shown in the sketches to the right). Through this process, It became clear that to fully optimise step-in height, it would be beneficial for such a system to allow the vehicle to lower completely to road-level. When discussed in expert interviews, both experts confirmed the conceptual feasibility of this idea, suggesting that the underside of the vehicle could be protected from uneven road surfaces through rubber feet at each corner of the vehicle, or an automated levelling system that detects and compensates for the road surface.

Although offering a promising solution to reducing step-in height, the additional wheelhouse volume required to accommodate the increased suspension travel creates additional challenges for SAV layouts with seating above the wheels. In these cases, simply incorporating a kneeling suspension system to reduce floor height can create a feedback loop whereby the additional wheelhouse height raises the height of seating above the wheelhouses and actually necessitates a raised floor height to keep a suitable distance between the seat pan and the vehicle floor.

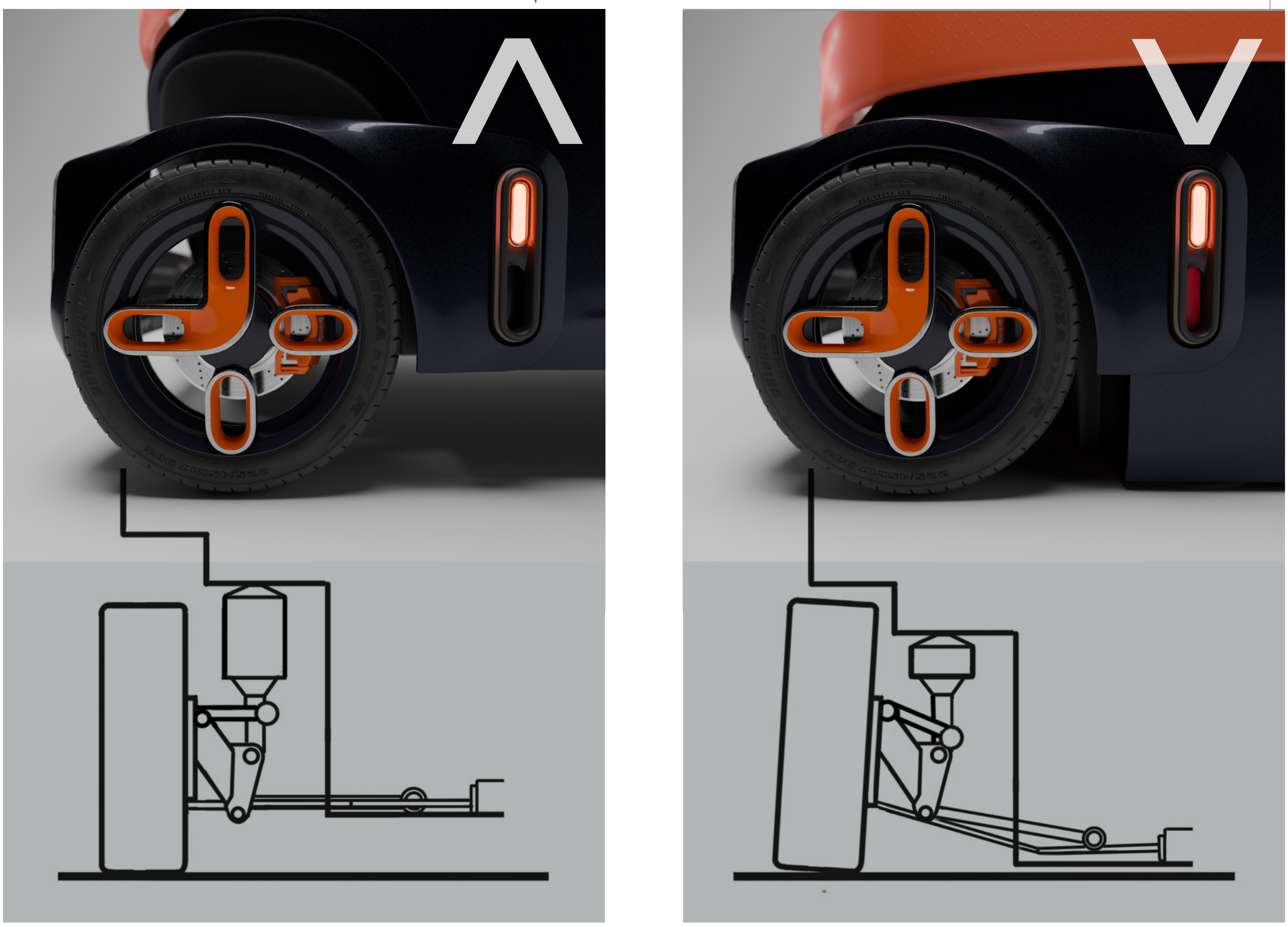
To address these issues, a concept for a wheelhouse and suspension design was created which would allow for additional suspension travel but only when in a parked position with the wheels parallel. The images and illustrations on the right show this concept utilising a kneeling suspension configuration based on that shown in TUMCREATE's DART concept (TUMCREATE, n.d.).

This stepped wheelhouse design would limit the encroachment of the additional wheelhouse height to a narrow portion at each side of the vehicle, allowing most of the wheelhouse to remain low enough to allow for passenger seating. For the example of a vehicle with 650mm wheel diameter discussed previously, this would require the suspension to lower by the 100mm allowed in the original wheelhouse, plus an additional ~130mm (or less to account for a small gap between road and vehicle). Assuming a rebound of 80mm in normal operation (as allowed for in DART's suspension system (TUMCREATE, n.d.)), this would require a total suspension travel of 310mm.

When discussed with E2, this concept was considered to be a potentially viable solution in allowing the packaging interior seating. However, as a novel concept with no comparable existing use-cases, it is unclear whether suitable air suspension components and configurations are currently available to allow this amount of travel. As an aim of these design is to stimulate further research, this concept is included in the SAV design to prompt further consideration of its feasibility. In any case, the addition of this feature to the concept does not impact the validity of any additional design work as vehicle layouts, features etc. built on this platform could equally apply to a vehicle with a longer wheelbase which allows for a lower default floor height and provides the same usable interior envelope with seating in front of the wheels.



Initial SAV ramp and kneeling suspension ideation sketches



SAV kneeling suspension and wheelhouse design concept

INTERIOR STANDING HEIGHT

Another key inclusive design consideration in the development of the basic SAV package included the requirement for unobstructed, standing space inside the vehicle, suggested by mobility impaired participants to enable easier movement after boarding.

The 2800mm vehicle height afforded by the benchmarked SAV dimensions provide ample height of 2220mm inside the vehicle- accounting for a floor height of 380mm and a roof thickness/ curvature of ~100mm. This more than accommodates the global 99th%ile height of 2004mm (DINED database (Molenbroek, 2018)).

Several other SAV platform considerations e.g. door location and passenger occupancy are less separable from other areas of inclusive vehicle design and so are described in further detail throughout the following design-focused sections.

PARAMETRIC DESIGN TOOL FOR SAV PLATFORMS

Given the number of competing priorities in the design of an inclusive SAV platform, it can be difficult to arrive at a suitably optimised and feasible vehicle platform that allows for efficient use of space, easy boarding for wheelchair users and other disabled people, and acceptable proportions. While attempting to design such a platform on which to base further design practice, the manual process of iterating potential platform designs through sketching and calculating key dimensions including ramp angles, seating height, sill depth etc. proved time consuming.

To aid the planning of SAV packaging, parametric design tools can be used to generate 3D package models (König et al., 2021; Sethuraman et al., 2020). These existing tools, however, tend to focus on the efficient packaging of vehicle systems and seating and do not illustrate how the package influences ramped boarding- a key inclusive design consideration. Such tools are also not widely available- requiring the use of specialist engineering software, and do not allow for the real-time iteration of vehicle packages which can be beneficial to vehicle designers wishing to fine-tune or test certain proportions and parameters.

To allow for rapid iteration of potential platforms and illustrate the impacts of packaging decisions on ramped boarding, a parametric design tool was created which generates and updates a 3D model of an SAV platform in response to real-time adjustments of several key parameters. Some key assumptions were made during the design of the tool including:

Seating layout - The packaging of seating at the front and rear of the vehicle, above or in front of the wheelhouses. This has already been identified as the most efficient AV seating layout (König et al., 2021) and features in multiple existing SAVs. For larger vehicles, such as that on which this project focuses, additional seating may be placed between the wheelhouses. Such seating is not generated by the tool as it is not directly influenced by the design of the vehicle platform and may be positioned by vehicle designers in a variety of ways.

Ramp entry - Use of a ramp for wheelchair access, rather than providing level boarding platforms, or wheelchair lifts.

Packaging of vehicle systems - Vehicle systems including powertrain components and batteries were not incorporated within the tool as the impact of these systems on the overall vehicle exterior and interior dimensions of a mid-sized SAV was assumed to be minimal. Such systems can generally be packaged in the space between the wheels- for powertrain and steering components and batteries, under the floor- for batteries, or in the roof- for heating, ventilation and air conditioning (HVAC) systems. This is demonstrated in TUMCREATE’s (n.d.) DART design.

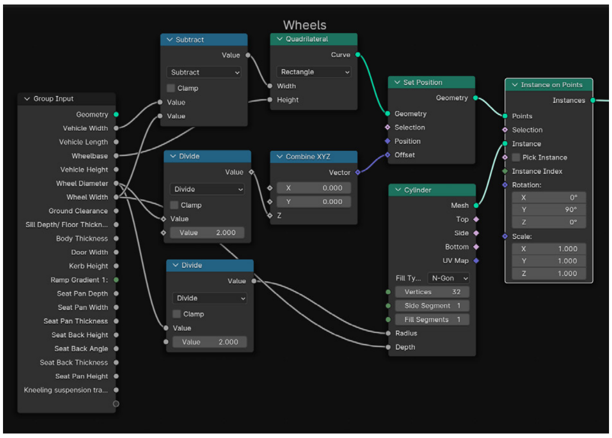
Design and functionality of the tool

To enable wider use by designers without access to, or experience with engineering-based CAD packages (e.g. Catia V5, used for Sethuraman et al.'s tool (2020)), the tool was created using the "Geometry nodes" function of Blender- a free open source 3D modelling software (Blender Foundation, 2023). This function uses a node graph system to procedurally generate 3D geometry according to defined input parameters.

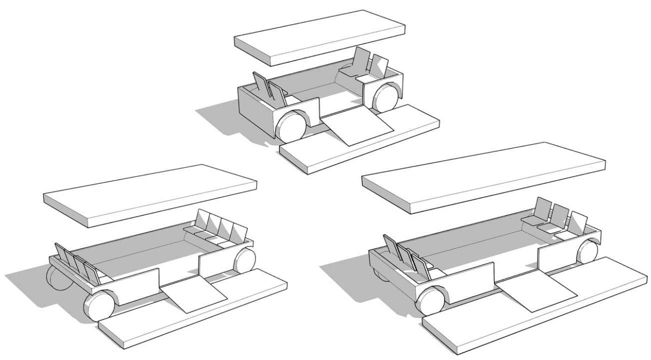
The image on the right shows an example of a geometry nodes tree created for this tool, in this case used to define the shape of the vehicle's wheels- according to a defined diameter and width, and the position of the wheels- according to a defined vehicle width and wheelbase.

The tool allows for the input of 20 key SAV dimensions related to the vehicle platform design, the shape of the seat, the dimensions of the ramp, and the presence and height of a kerb inputs can be seen on the right of the screenshot below.

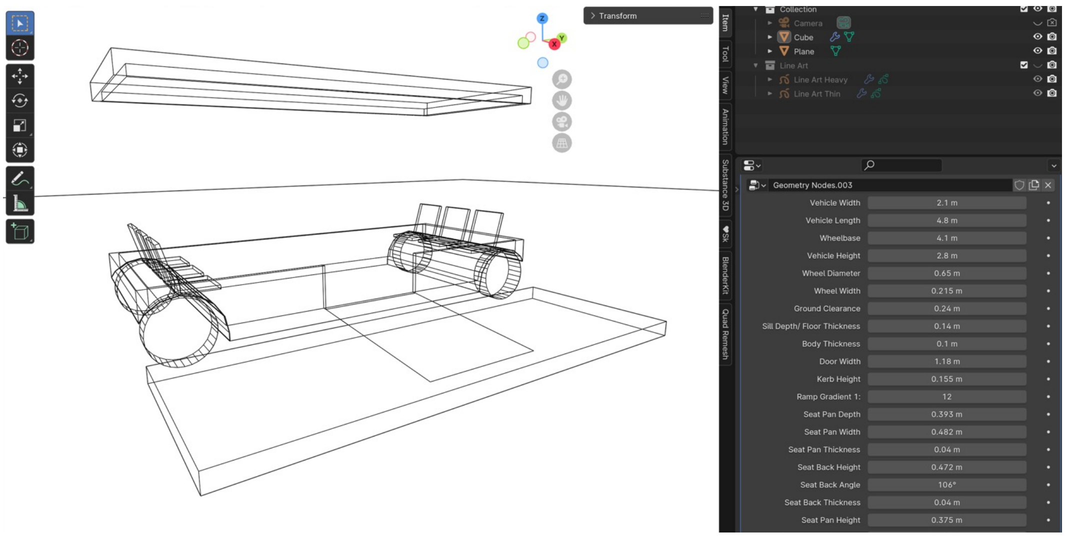
The output 3D mesh can be used as the basis for further design development both in 3D - as a reference geometry for more detailed 3D models, or as an underlay for sketch development of vehicle interiors or exteriors (as shown above).



Blender interface (Blender Foundation, 2023) showing a portion of the parametric platform design tool geometry nodes set-up.



Range of potential outputs from parametric platform design tool.



Blender interface (Blender Foundation, 2023) showing parametric platform design tool including platform wireframe (left) and parameter input (right).

FINAL SAV PLATFORM DESIGN

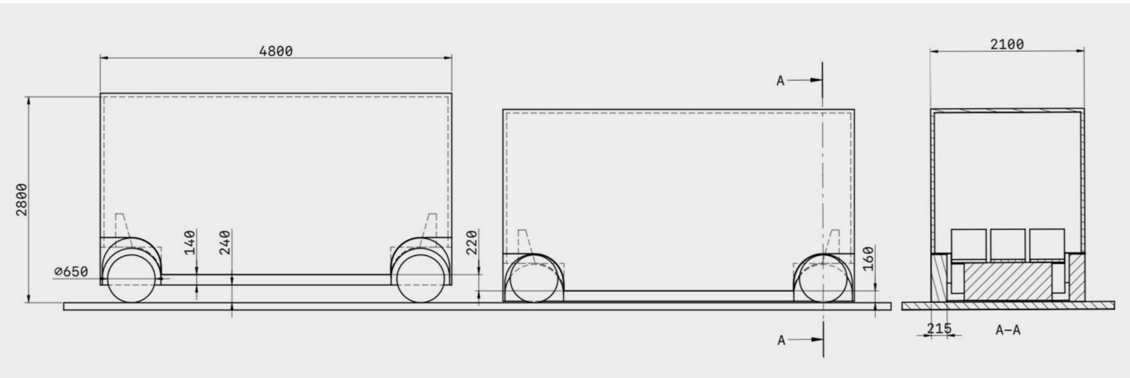
Given the design-led nature of this project and the limited engineering experience of the researcher, the vehicle packaging developed in this section has been restricted to that which directly impacts on key inclusive design considerations, namely lowering the vehicle floor and allowing for ease of movement inside the vehicle.

The ultimate aim of this part of the project was to develop a conceptually feasible platform on which to base further interior and exterior vehicle designs. Because of this, the packaging of vehicle systems without a direct impact on inclusion or the interior space has not been fully explored. Rather, based on the designs of existing SAV packages e.g. Steel E-motive and DART (Steel E-Motive, 2023; TUMCREATE, n.d.). These systems have been assumed to be feasibly packaged within the existing envelope without significant additional interior encroachment.

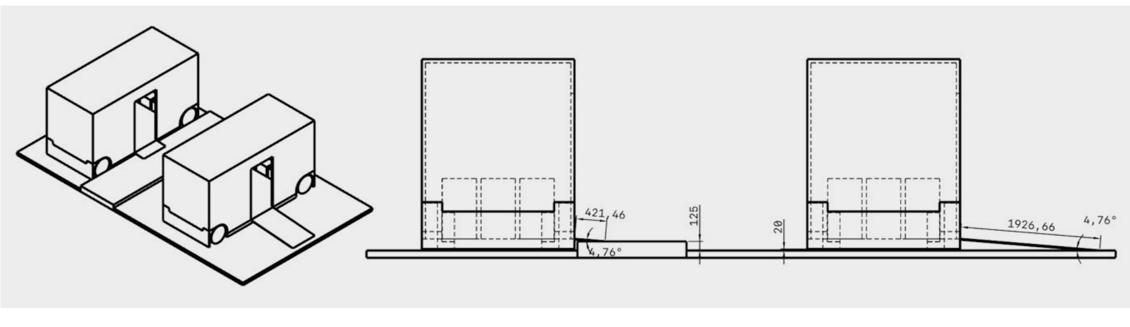
The images on the right show the vehicle platform created in the SAV platform design tool as a basis for further SAV design work. The images demonstrate the vehicle in kneeling and upright modes and the impact this has on the length of a 1:12 ramp used from road-level or a 125mm kerb. The exact input parameters can be seen alongside each image.

Although the tool does not incorporate the kneeling suspension wheelhouse concept described above, the interior encroachment of such a design can be seen in images 1 and 2, where the wheels can be seen to pass through the wheelhouses on either side of the seating.

Images below show the key dimensions of the vehicle platform including required ramp lengths to reach both ground and kerb height at an angle of 4.8°. The image on the following page shows how these elements of package design are incorporated into the design of the concept inclusive SAV.

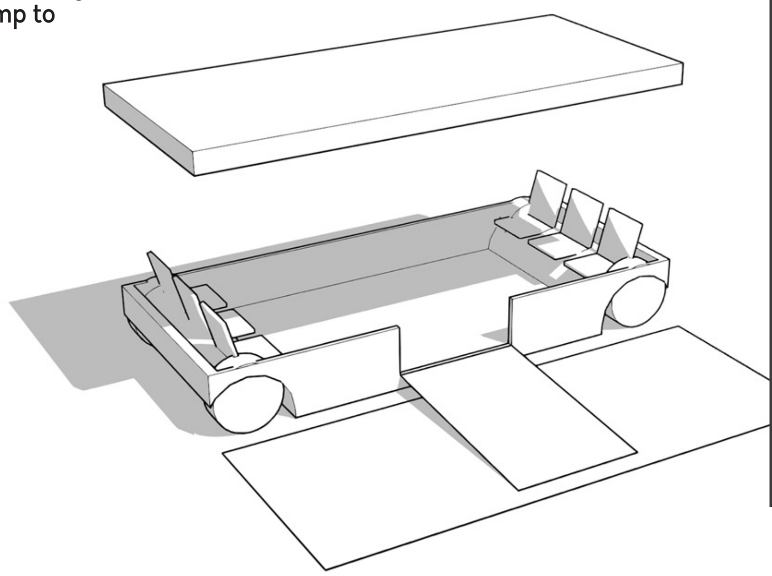


SAV platform dimensions in raised and kneeling positions



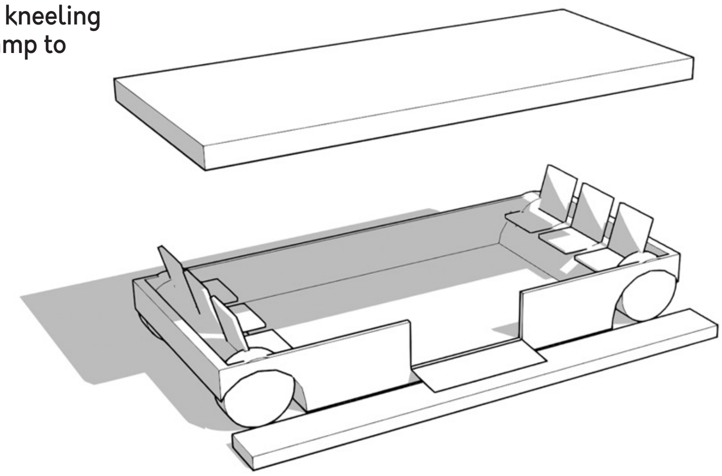
SAV ramp dimensions to ground and kerb heights

1. SAV kneeling with ramp to ground



Vehicle Width	2.1 m
Vehicle Length	4.8 m
Wheelbase	4.1 m
Vehicle Height	2.8 m
Wheel Diameter	0.65 m
Wheel Width	0.215 m
Ground Clearance	0.24 m
Sill Depth/ Floor Thickness	0.14 m
Body Thickness	0.1 m
Door Width	1.18 m
Kerb Height	0 m
Ramp Gradient 1:	12
Seat Pan Depth	0.393 m
Seat Pan Width	0.482 m
Seat Pan Thickness	0.04 m
Seat Back Height	0.472 m
Seat Back Angle	106°
Seat Back Thickness	0.04 m
Seat Pan Height	0.375 m
Kneeling suspension travel	0.22 m

2. SAV kneeling with ramp to kerb



Vehicle Width	2.1 m
Vehicle Length	4.8 m
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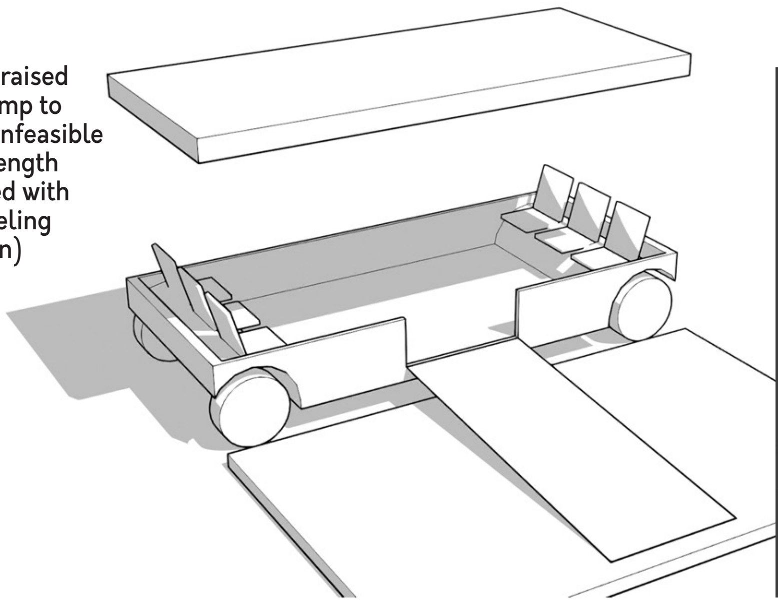
Vehicle Height	2.8 m
Wheel Diameter	0.65 m
Wheel Width	0.215 m
Ground Clearance	0.24 m
Sill Depth/ Floor Thickness	0.14 m
Body Thickness	0.1 m
Door Width	1.18 m
Kerb Height	0.125 m
Ramp Gradient 1:	12
Seat Pan Depth	0.393 m
Seat Pan Width	0.482 m
Seat Pan Thickness	0.04 m
Seat Back Height	0.472 m
Seat Back Angle	106°
Seat Back Thickness	0.04 m
Seat Pan Height	0.375 m
Kneeling suspension travel	0.22 m

3. SAV raised with ramp to kerb (unfeasible ramp length required with no kneeling function)



Vehicle Width	2.1 m
Vehicle Length	4.8 m
Wheelbase	4.1 m
Vehicle Height	2.8 m
Wheel Diameter	0.65 m
Wheel Width	0.215 m
Ground Clearance	0.24 m
Sill Depth/ Floor Thickness	0.14 m
Body Thickness	0.1 m
Door Width	1.18 m
Kerb Height	0.125 m
Ramp Gradient 1:	12
Seat Pan Depth	0.393 m
Seat Pan Width	0.482 m
Seat Pan Thickness	0.04 m
Seat Back Height	0.472 m
Seat Back Angle	106°
Seat Back Thickness	0.04 m
Seat Pan Height	0.375 m
Kneeling suspension travel	0 m

SAV KNEELING AND RAMP DEPLOYMENT

INTERIOR DESIGN

The following section includes concepts for more inclusive SAV interior design in the areas of:

- Vehicle layout
- Seating design
- Interior navigation and movement
- Luggage, storage, and occupancy

The interior of the SAV is unsurprisingly the area where most inclusive vehicle design interventions might be made, given the proportion of a journey spent inside the vehicle. The following section details the process of designing a more inclusive SAV interior inside the vehicle envelope defined in the previous section. It discusses how the design developed through this process prioritises and manages trade-offs between the needs of a variety of transport excluded groups. Areas explored include vehicle layout, seating design, storage, and guidance systems for visually impaired people.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INCLUSIVE DESIGN CONSIDERA

WHEELCHAIR SPACE

Provide access to sufficient wheelchair space(s)

Reduce potential for wheelchair space to be occupied

Ensure easy, independent use of suitable wheelchair restraints- if required

Allow suitable seating for wheelchair users' travelling companions

SEATING

Seating orientation allowing for different levels of social interaction according to preferences

Seating orientation allowing forward facing for comfort

Seating orientation allowing facing to aid communication for hearing impaired people through British Sign Language (BSL) and lip reading

Seating layout ensuring sufficient leg room for comfort

Seating layout divided to improve sense of security from other passengers

Seating allowing for multiple preferences for comfort

Seating adaptation e.g. folding requiring little strength/ dexterity

Adjacent seat division to improve sense of security from other passengers

Priority spaces allowing access to inclusive features if not available at every seat

ATIONS

ADAPTABLE/ FLEXIBLE INTERIOR SPACE

Allow passengers to reserve and adapt interior space to meet their access needs

Adaptable interior automatically returns to default accessible position i.e. clears space for wheelchair users

NAVIGABLE VEHICLE INTERIOR

Incorporates Intuitive, tactile means of guiding visually impaired people through the vehicle

Make the location of interior features obvious to visually impaired people

Provide support for disabled people when moving in the vehicle

LUGGAGE/ ASSISTANCE ANIMAL SPACE

Space for personal items close to seat, in line-of-sight, or in contact with passenger to reduce fear of theft

Space for large luggage that doesn't require significant strength to place

Space for assistance dogs near to seating

FACILITATING ON-JOURNEY ACTIVITIES

Facilitating use of personal devices and reading

Providing useful, pleasant and surprising features to all passengers

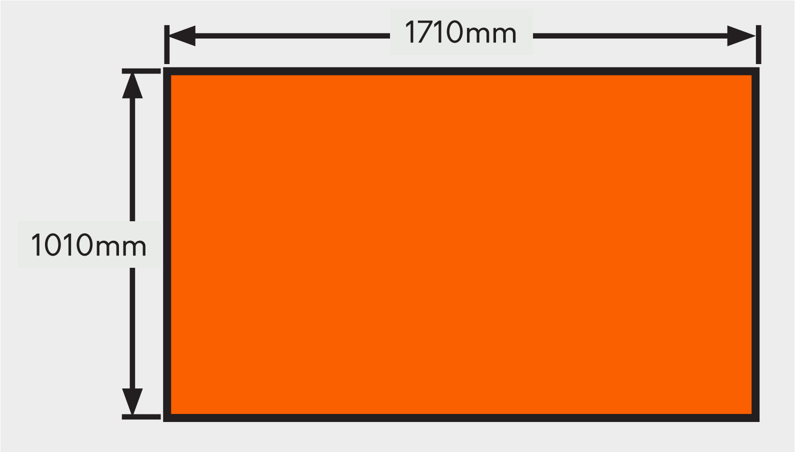
INTERIOR LAYOUT – WHEELCHAIR OCCUPANCY

Wheelchair users' interactions with and use of the physical elements of the vehicle interior present some of the most significant challenges and differences in design requirements. The space needed to move and position a wheelchair onboard an SAV has major implications on the layout of the vehicle. As SAVs offer a relatively blank slate for interior configuration, it was beneficial to begin the interior design process by determining the positioning and size of the wheelchair space and the route to and from the vehicle door. After the positioning for the wheelchair space was determined further development sought to position seating and other interior features around this space.

WHEELCHAIR SPACE SIZING

Wheelchair sizes can vary significantly and to be fully inclusive of this range, SAVs may need much larger spaces than the 1300x750mm currently required in the UK (The Public Service Vehicles Accessibility Regulations, 2000b). According to Bharathy and D'Souza's (2018) web-based tool, this UK standard space would only accommodate 72% of wheelchair users. To accommodate all wheelchair users, a space of 1710x1010mm is required (Bharathy and D'Souza, 2018). These dimensions have been used to define the size of the wheelchair space in the concept SAV developed during this project.

While the SAV platform design provides plenty of available floor space, the positioning of the wheelchair space is key to ensure wheelchair users' other requirements and desires are met. While many public transport vehicles currently require wheelchair users to face towards the rear of the vehicle, the discomfort that this causes, the general preference for forward facing seating among many workshop participants, and evidence that rear facing seating causes motion sickness in SAVs (Salter et al., 2019) informed a decision to incorporate a forward-facing wheelchair space.



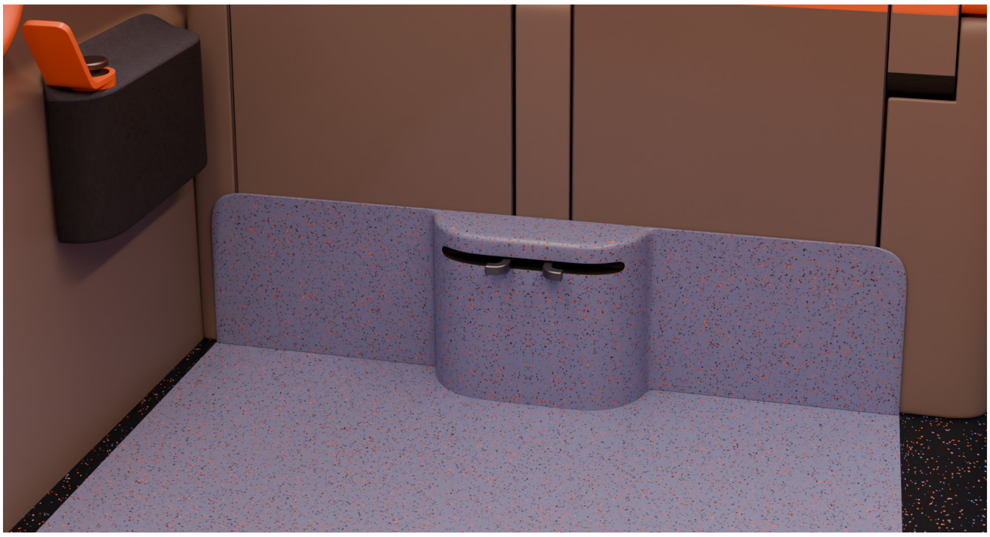
Wheelchair space dimensions to accomodate all wheelchair users from Bharathy and D'Souza's (2018) sample.

WHEELCHAIR RESTRAINT SYSTEM

Rear-facing spaces are typically used in public transport vehicles to avoid the need for complex wheelchair restraints while providing a degree of safety in collisions. For a forward-facing space, a wheelchair restraint system is more likely to be necessary. This system should be independently usable by wheelchair users given the absence of a driver to assist.

Several restraint systems exist that seek to provide independent operation for wheelchair users. These include systems that require brackets to be retro-fitted to the wheelchair e.g. Q'straint's QLK (Q'STRAINT, 2024a) and the universal docking interface geometry (UDIG) (Hobson and Van Roosmalen, 2007) as well as systems that can adapt to multiple wheelchairs without the need for additional fittings e.g. Qstraint's Quantum system (Q'STRAINT, 2024b)- utilising an automated arm to exert pressure on the sides of the wheelchair an hold it in place (only usable as additional restraint in rear-facing spaces).

Due to the complexity of these systems, the concept SAV design assumes the use of a UDIG system, rather than seeking to incorporate a new design. The UDIG system was selected as it allows forward facing travel and can be fitted into a vehicle wall/ folding seat assembly without any floor-located components that could cause obstructions or trip hazards for other passengers- as with the Q'straint QLK. Although UDIG provides one potential route to providing independent use of the wheelchair restraint system, the ideal system would be a similarly secure and truly universal system i.e. not requiring the adaptation of wheelchairs. It may also be possible that certain SAV use cases- e.g. operating at low-speeds in dedicated areas- might reduce the risk and effects of crashing and remove the requirement for these systems.



Visualisation of a UDIG restraint system in the concept inclusive SAV design.

WHEELCHAIR SPACE POSITION AND MANOEUVRABILITY

Having determined the size and orientation of the wheelchair space, it is necessary to ensure it is suitably positioned within the vehicle. Several factors influence the location of this space including:

Meeting the needs of wheelchair users - being easy to manoeuvre to from the vehicle door, and providing nearby seating to aid conversation with travelling companions.

Meeting the needs of other excluded groups - ensuring clear routes to other seating for visually impaired people and allowing for division of interior space to improve perceptions of security.

Allowing for general SAV requirements - Maximising passenger occupancy and maintaining access to other seating.

As the design of the concept SAV assumes a single side entrance from the pavement (common in SAV designs) the positioning of the wheelchair space should be on the side of the vehicle opposite the doors. This allows for a clear area for moving in the length of the vehicle to access seating at either end, while reducing the potential that longer wheelchairs could block part of the entryway. The position of the space in the length of the vehicle can then be determined according to the ease of manoeuvring into the space and the availability of suitable nearby seating that enables wheelchair users to converse with fellow travellers.

The variability of wheelchair designs, makes it difficult to predict exactly how every wheelchair user might navigate to the space. As well as differences in length and width, the location of the centre of a wheelchair's turning radius can also vary. This is often located towards the rear of manual wheelchair, but may be at the front, centre, or rear of a powered wheelchair.

Perhaps due to this vast range of potential configurations and sizes, there is limited available information about the exact ways that wheelchair users might move through a space, particularly a confined space such as a vehicle interior. Regulations which seek to ensure suitable manoeuvring space often adopt measures that do not accurately account for the real motion of an independently operated wheelchair. With regulations defined by pushing a 'reference wheelchair' into position - which cannot accurately replicate independently operated wheelchair motion (The Public Service Vehicles Accessibility Regulations, 2000b) - or minimum turning radii which assume manoeuvres are limited to a simple turn around a single point (The Building Regulations, 2010).

Theoretically, a turning radius could be useful if the wheelchair space was centrally located in the vehicle width, allowing a wheelchair user to position themselves in the centre of the vehicle, rotate 90° about this point, and reverse into a space. In reality, however, the other factors discussed previously dictate an offset position for the wheelchair space, requiring less predictable manoeuvres. In addition, assuming a central pivot point, the 1710x1010mm wheelchair dimension determined above would require a minimum turning circle of 1986mm (dictated by the diagonal dimension of the wheelchair footprint). This turning circle could not be accommodated within the maximum 1900mm interior width determined by the SAV platform, indicating the need to provide for more realistic, space-efficient manoeuvres that utilise the length of the vehicle for turning and reversing manoeuvres.

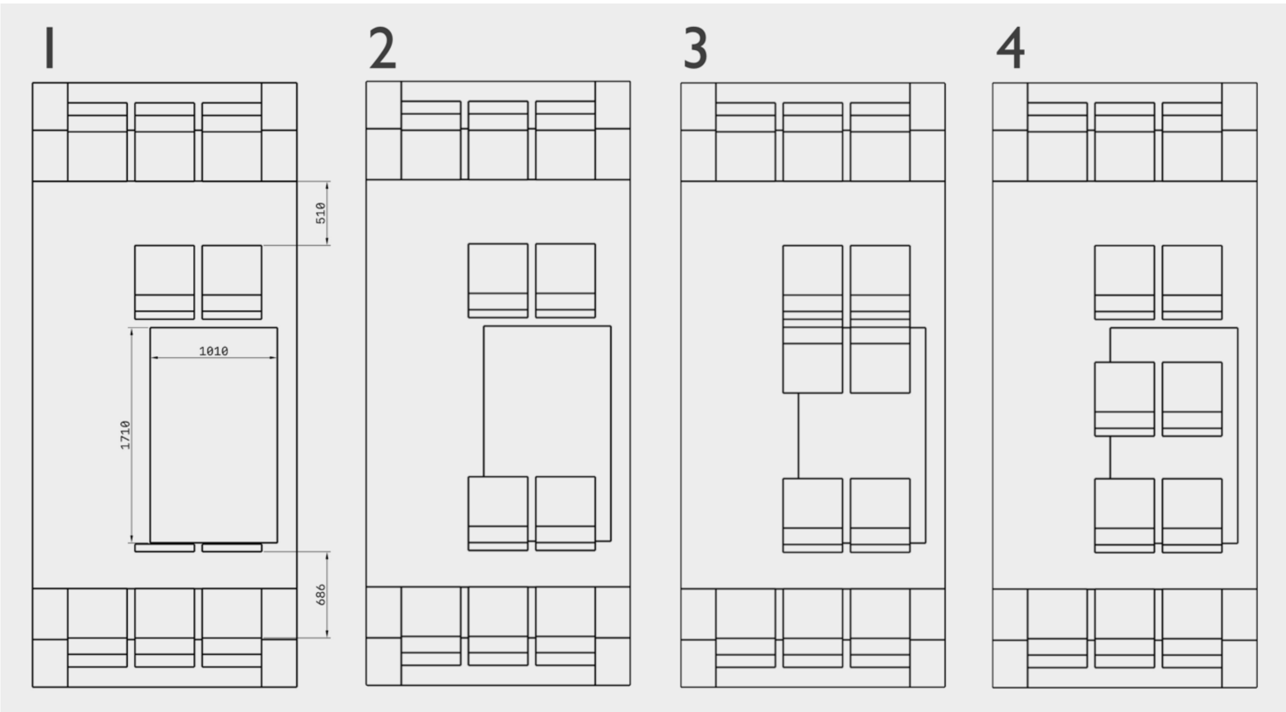
The focused workshop with WU1 tested manoeuvring into a wheelchair space in a marked out section of floor, and demonstrated the more complex nature of the paths that wheelchairs follow to move into location. With WU1's movements in his manual wheelchair combining curved paths, pivoting, and reversing. During this workshop, WU1 tested manoeuvring from a central doorway to two potential wheelchair space locations. WU1 found it easier to manoeuvre to a wheelchair space towards the front of the vehicle than one towards the back due to the simple set of movements demonstrated in the lower set of images and diagrams on the following page.

A rear-positioned space was still possible for WU1 to move into but required an additional manoeuvre to spin the chair once in position (Step 2 in the first set of images on the following page). Both positions required a simple left turn to disembark the vehicle.

The two wheelchair space locations tested in this workshop assumed a central door position. During the analysis of this workshop, it became clear that the ease of manoeuvring to the forward-positioned space, was not solely due to its location in the vehicle, but because of its position relative to the door- with the back of the space roughly parallel to the door. This relative positioning allows for alternative layouts with the doorway positioned towards the rear of the vehicle and the wheelchair space positioned centrally.

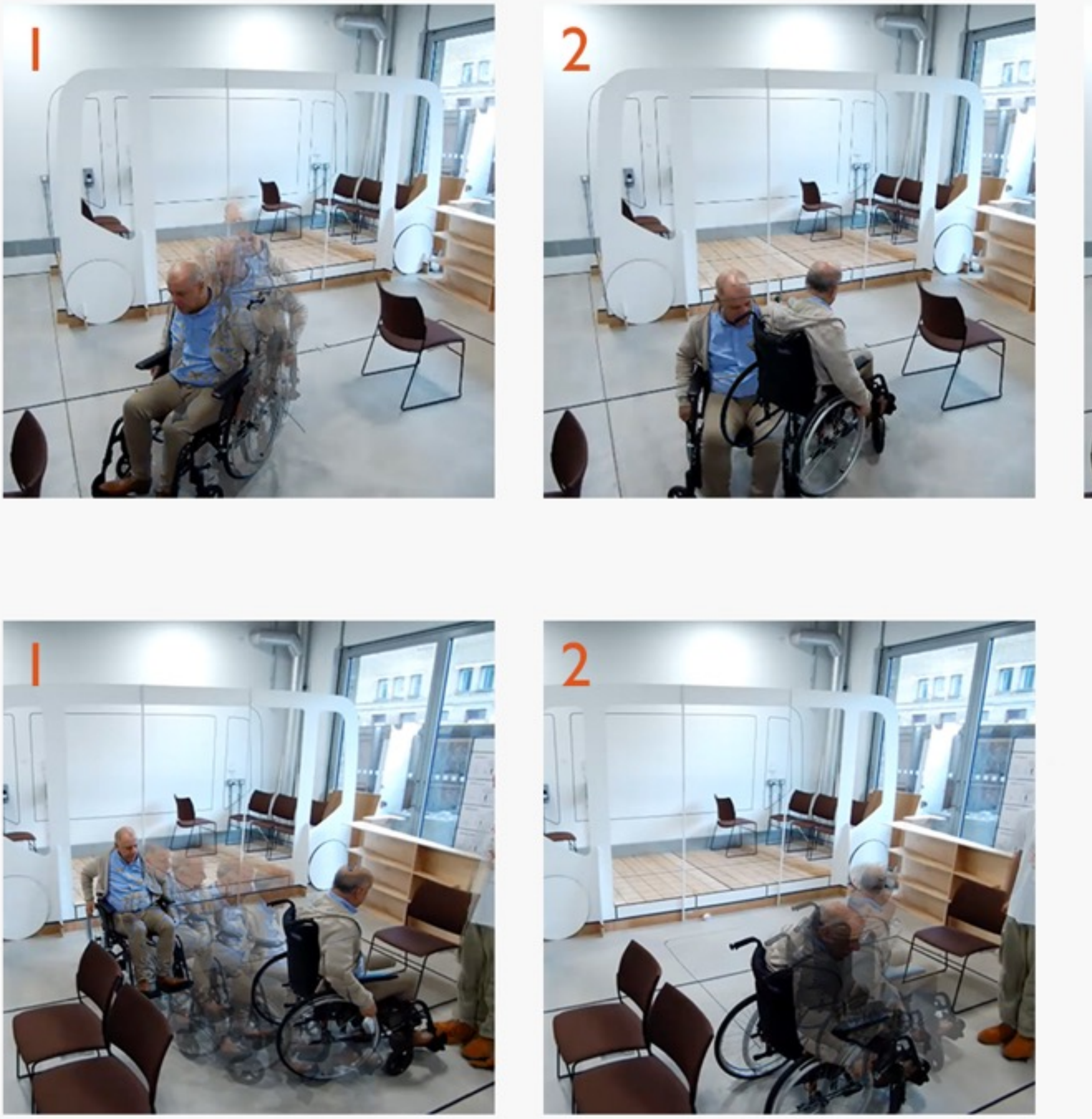
Such a configuration would allow for a row of 2 folding seats at the rear of the wheelchair space, in front of the rearmost row of seats and another row of two seats positioned at the front of the wheelchair space. To maximise passenger comfort, it is beneficial for these two rows of seats to face forwards, allowing a total of 7 forward facing seats, and 3 rear-facing seats at the front of the vehicle.

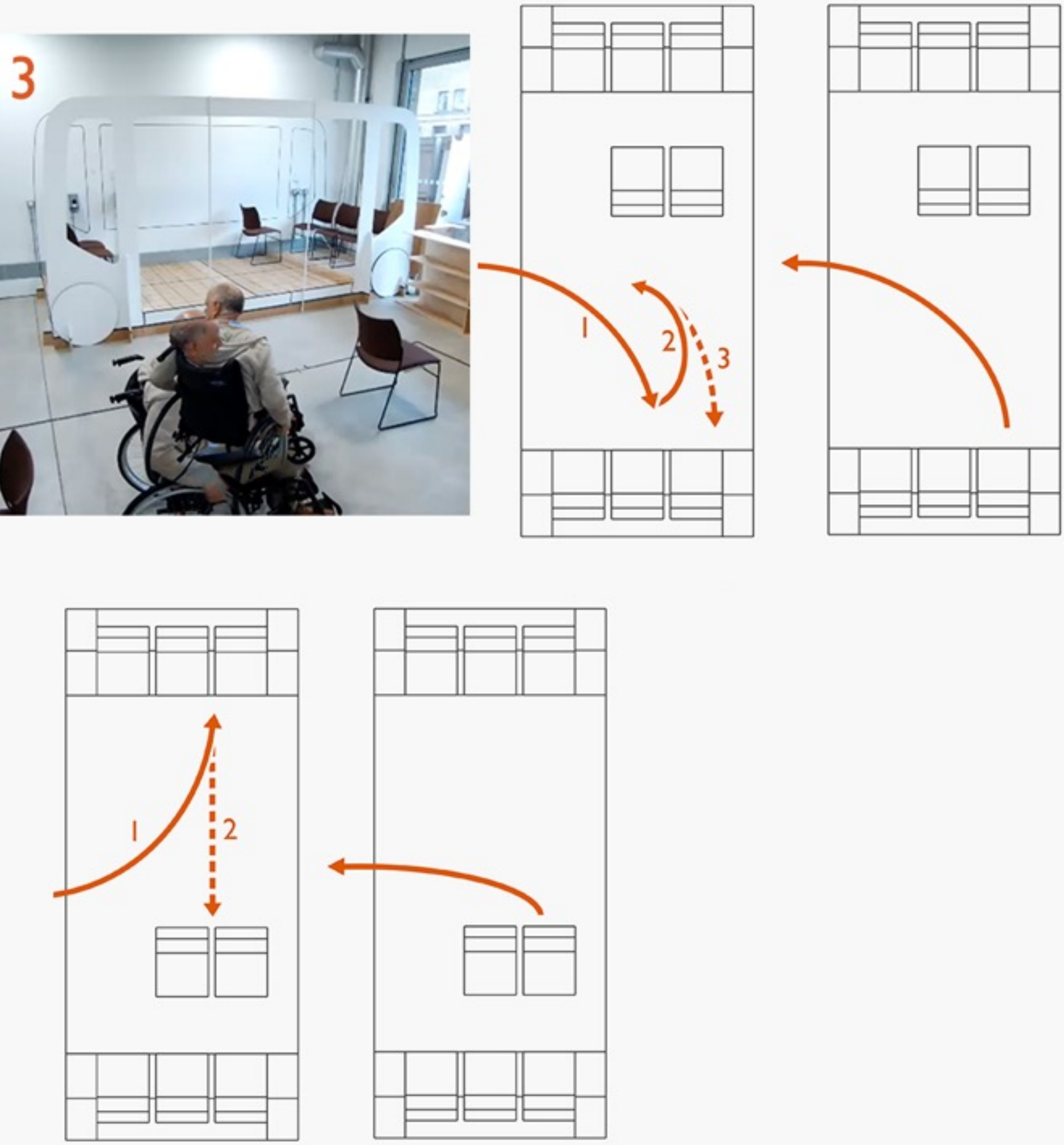
To test the feasibility of this configuration, a basic layout model was created in Shapr3D (Shapr3D Zrt., 2024). This model assumed a minimal seat back thickness of 60mm, legroom between facing seats of 510mm (as recommended by Fiorillo et al. (2021)), and a pitch (the distance between rear of seat pad and knee) of 686mm between the rear seats and folding seats (equivalent to 95th %ile Netherlands male's Buttock-Knee depth as suggested by Vink (2016)). Images 1 & 2 (below) show this potential layout with the seats folded and unfolded. Images 3 and 4 indicate the ways in which the interior space could be utilised if the wheelchair space were not present or if additional folding/ moving seating was incorporated into the design.



SAV Wheelchair space location and potential seating layouts.

TESTING WHEELCHAIR MANOEU-VRABILITY




3
1
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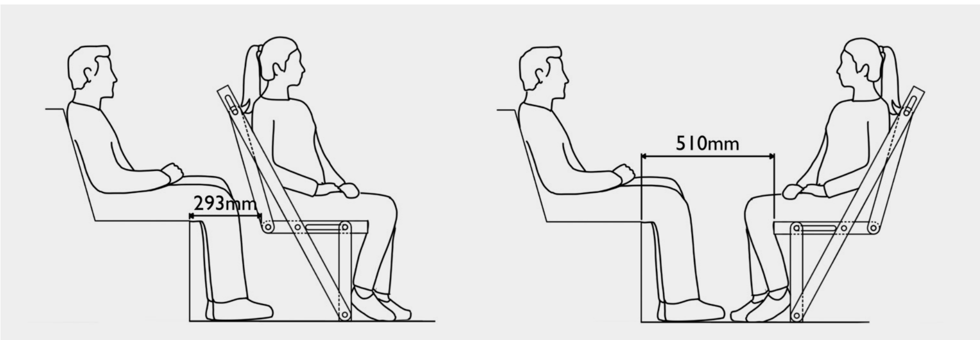
1
2

REVERSIBLE FOLDING SEATING:
CREATING SPACE & ALLOWING CONVERSATION

While the layout proposed above could feasibly provide a wheelchair space of 1710x1010mm between the seats, additional length would be needed to manoeuvre a wheelchair into this position and no nearby seating would be available for wheelchair users to socialise with fellow travellers (a key requirement discussed by WU1). To meet these requirements while retaining a layout that maximises the potential for forward facing passenger occupancy, it was determined that reversible folding seating should be provided which allows the seats to be used facing forwards when the wheelchair space is not in use and facing backwards to allow conversation between the wheelchair user and fellow travellers, once the wheelchair is in position.

Reversible seating has previously been used in public transport contexts such as trams and trains to allow passengers to face the direction of travel. These seats often incorporate a fixed seat pad with a pivoting double-sided seat back. As a fixed seat pad would extend into the wheelchair space, this style of seat would not provide additional space at the front of the wheelchair space. Instead, a seat was designed which would allow the whole seat to fold flat in a central position when not being used.

The design of this seat also ensures that wheelchair space length is maximised even when the seating is in use. A pivoting seat pad changes the distance between the seat pad and the vehicle's front-most rear-facing seats to accommodate the different legroom needed for both forward and rear facing configurations. In the forward-facing position, passengers require more leg room (510mm as recommended by Fiorillo et al. (2021)) as they may be facing the rear-facing passengers in the front row of seats. In the rear-facing position, the reversible seat can be positioned closer to passengers in the front row of seats, as these passengers would be able to stretch their legs underneath the reversible seat. The proposed mechanism and impacts on leg room are shown in the images below.



Variable leg room allowed by the reversible seat design.

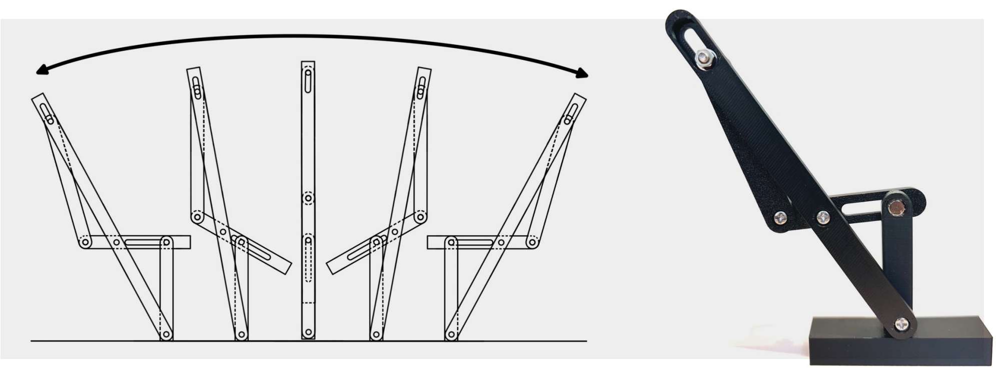


Diagram and 3D printed model of reversible seat mechanism.

The design of the seat is intended to allow for easy manual use, with the back of the seat providing a large lever that can be pulled or pushed into the correct position. While an electro-mechanically actuated equivalent to this design is possible, this simpler, manual manipulation was selected to reduce the potential for faults in these more complex systems resulting in the obstruction of the wheelchair space. As reaching and folding the seats might not be possible for a wheelchair user themselves, the seats would be sprung to return them to a central position after the seated passenger departs (as suggested by a wheelchair user during the workshops).

Reversible seat design shown in 3 positions.

REVERSIBLE FOLDING SEATING:
VEHICLE LAYOUTS AND DIMENSIONS

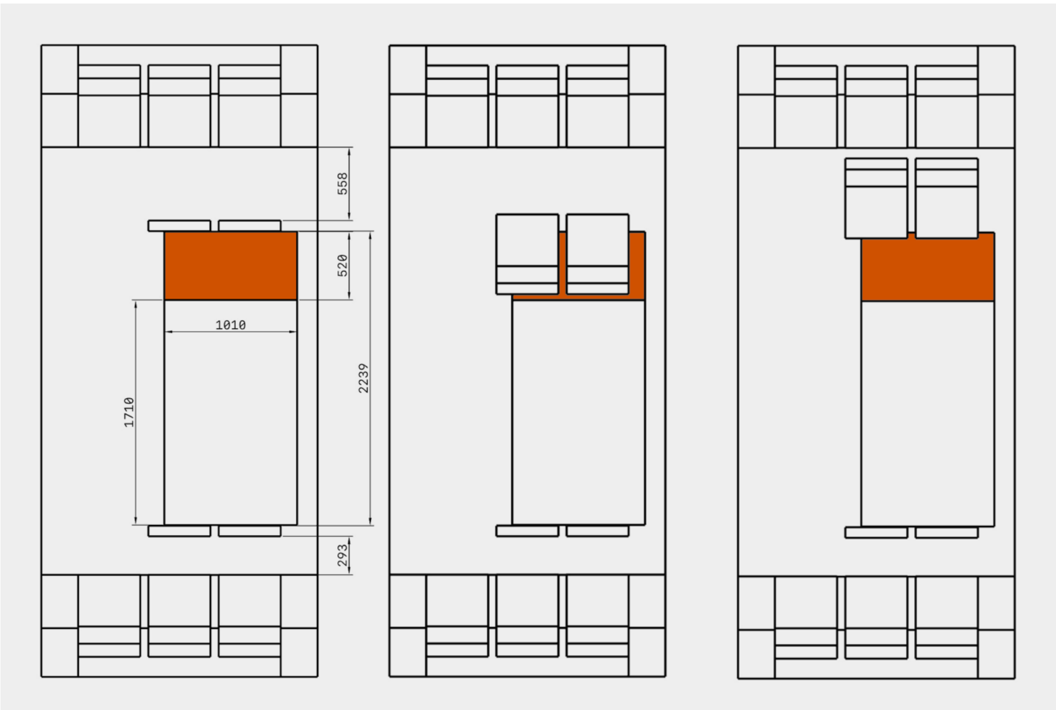
The layouts below demonstrate the overall impact of the reversible seating design on the amount of available wheelchair space for manoeuvring, with the dimensions for seating, wheelchair space and overall vehicle dimensions used in the design of the concept inclusive SAV.

To meet the seating requirements discussed previously, a 686mm pitch is required between seats facing the same direction, giving a minimum legroom of 293mm, in front of a seat pad that is 393mm deep. A 510mm distance is required between the front edge of facing seats.

The location of the pivot point on the seat pad is determined to ensure the difference between the lengths of seat pad on either side of the pivot is equal to the difference between required legroom in forward and rear facing configurations. The design of the seat is such that the position of this pivot point also determines the position of the seat when in an upright position. In this instance, a pivot point that is 88mm from the front of the seat pad in a forward facing configuration, positions the centre of the folded seat 598mm away from the edge of the front row of seats. Accounting for an 80mm depth of the seat in a folded position, this allows the forward-most point of the wheelchair space to be 638mm from the front edge of the available floor space.

The rear set of folding seats would be positioned at 373mm from the rearmost seats- also assuming 80mm thickness of folding seat assembly and 293mm leg room for the rear seats. The maximum length of the available wheelchair space is the distance between these two positions which, given a 3250mm floor space length, is 2239mm leaving roughly 500mm additional space for Bharathy and D'Souza's largest wheelchair measurement (Bharathy and D'Souza, 2018).

While this amount of clear floor space is theoretically possible with this pivoting seat design, different positioning might be required to meet other practical considerations such as providing additional space in front of front and rear seats to allow access.



Reversible seating positions and their impact on available wheelchair space.

FIXED FOLDING SEATING:
REDUCING WHEELCHAIR SPACE OBSTRUCTION

Fixed folding seating at the rear of the wheelchair space was also incorporated in to the inclusive SAV design to maximise seated occupancy when a wheelchair user is not on-board.

The low-profile seat design folds forwards from the rear of the wheelchair space, increasing its length and providing a fixed upright surface to back the wheelchair against and mount the UDIG wheelchair restraint apparatus.

Discussions with WU2 around the use of the wheelchair space by other passengers led to the concept of folding seating that is designed in a way that demonstrates the priority of the space for use by wheelchair users. Some wheelchair spaces on public transport vehicles achieve this (whether intentionally or not) through folding seating that is less comfortable than other available seats e.g. seats that folds down from upright to give an uncomfortable 90° seat back angle. As SAVs are much smaller than these public transport vehicles, folding seating in the wheelchair space makes up a larger proportion of the available seating and is more likely to be required by seated passengers. This increased utilisation makes discouraging the use of the folding seats by reducing comfort unviable.

Instead, the folding seating in this SAV design aims to reduce unnecessary occupation of the seating through design cues intended to 'nudge' passengers to choose other seats. The seats are designed to blend in with other interior surfaces when in their default folded position, indicating that the use of the space for seating is a secondary function and that wheelchair users have priority. The additional effort of folding the seat down may also serve to direct passengers to other, more immediately accessible seats. For pre-booked SAV journeys, where it is known that a wheelchair user will be boarding, a simple electronic locking mechanism could also be used to fix the seats in their folded position and seat reservation features could also be designed to only allow the reservation of these seats if all other seats are occupied.

Wheelchair space folding seating in folded and unfolded positions

INTERIOR LAYOUT – SOCIALISING AND COMMUNICATION

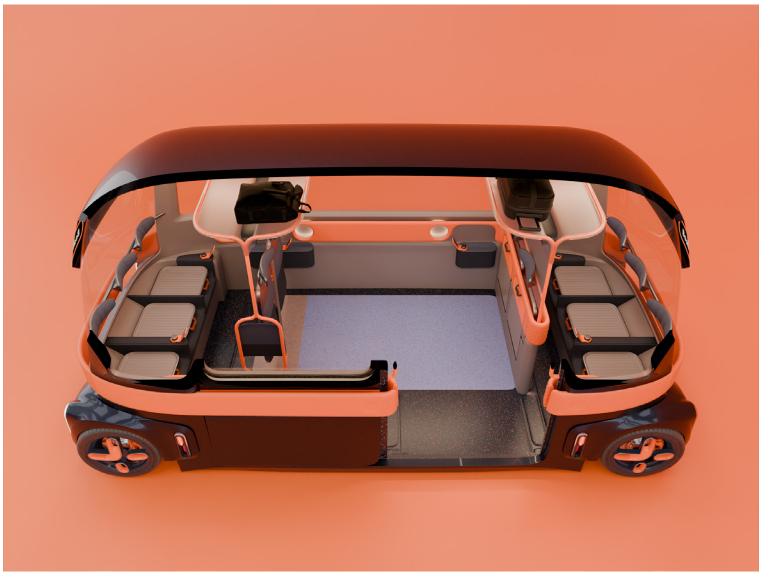
Several inclusive design considerations indicate a need for a degree of choice and variety in seating orientation and location relative to other passengers, allowing choices which might create more private or more social journeys.

The need for layouts which allow for socialising and communication with travelling companions were suggested by disabled people with impairments that might dictate their position in the vehicle or the position of those that they may wish to communicate with.

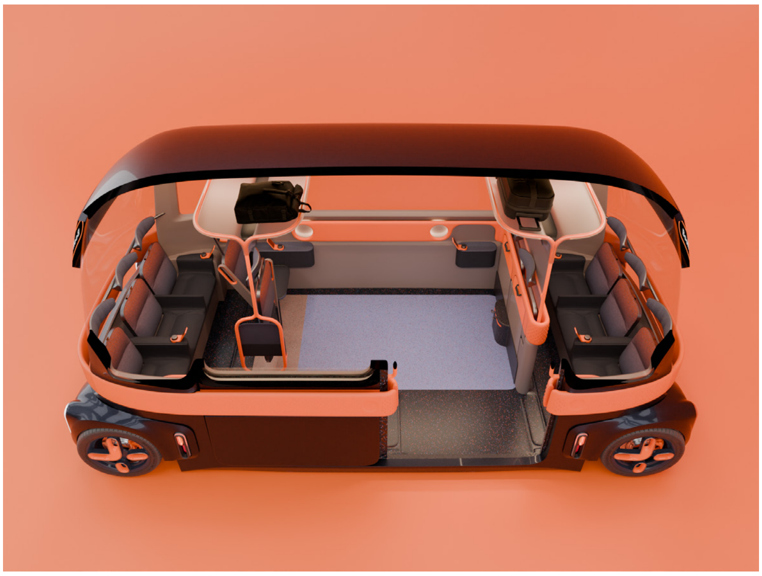
When testing within a mixed reality SAV environment, a wheelchair user (WU1) initially chose a seating position on the rear offside of the vehicle, selected according to his desire to sit in-line with a travelling companion. However, further testing of this position determined that the wheelchair space would need to be positioned in front of the back row of seats due to the wheelhouse location and any passenger sitting on the remaining available seat would be behind WU1, making conversation challenging. Discussed solutions to this included designing the passenger seat to move forwards to align with the wheelchair user or having folding seating in front of the wheelchair space- leading to the reversible seating design discussed previously.

The importance of seating layout in allowing for communication was also noted in a workshop with a hearing impaired participant, where facing seating was seen to aid non-verbal communication through British Sign Language (BSL) and lip reading.

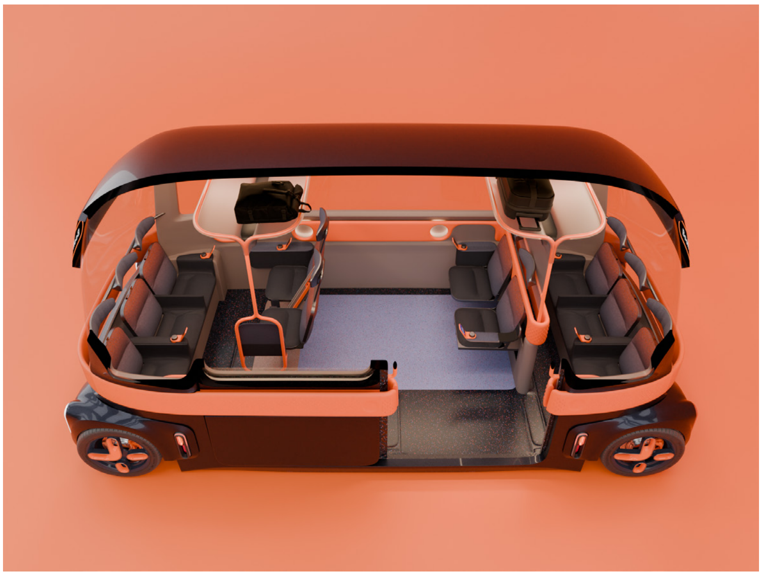
In the inclusive SAV design, the option for facing seating configurations is provided by the reversible folding seating. The adaptability provided by this seating allows for the configuration of two seating areas: a front area with 3 rear facing seats and up to 2 forward facing seats, and a middle seating area with a forward facing wheelchair space or 2 forward facing seats, and up to 2 rear facing seats.



SAV layout maximising cargo/ standing space.



SAV layout for wheelchair user facing a travelling companion in a reversible seat.



SAV layout maximising forward-facing seating.

INTERIOR LAYOUT – PRIVACY AND SECURITY

Issues of security when sharing the vehicle with strangers were a key concern of workshop participants- particularly women. Several discussions focused on how the layout and positioning of seating and dividing elements of the interior space might improve passengers' perceptions of security.

SEATING LAYOUT AND DIVISION

Dividing the entire interior space into different sections was suggested by workshop participants to provide a greater sense of security when sharing an interior space with strangers. In the workshops, various degrees of whole-vehicle division were discussed.

Although offering the most complete division, full height, opaque dividers such as screens or curtains were not favoured among participants as they reduced visibility of other passengers. Instead, mid-height, transparent or semi-transparent dividers were suggested to allow for passengers to experience a degree of separation from other passengers while retaining the ability to see, anticipate, and respond to negative passenger behaviours. The use of angled mirrors inside the vehicle was also suggested as a potential means of improving visibility of other passengers inside the vehicle.

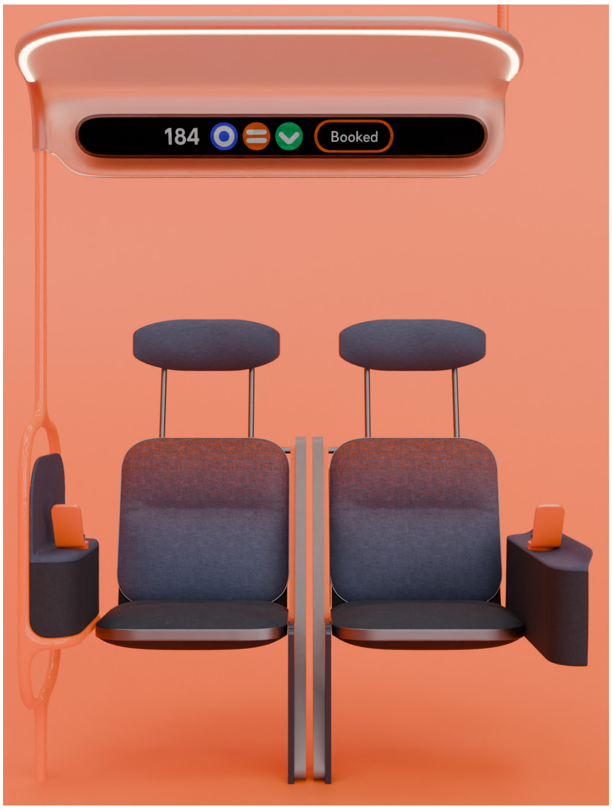
In the concept inclusive SAV, a divider separates reversible seating from the aisle space. A dividing screen is also positioned above the fixed folding seating, providing a division between the back row of seats and the rest of the vehicle. This divider is made from translucent material to provide a degree of privacy while retaining visibility of other passengers' movements.

As floor-to-ceiling division cannot be incorporated in the location of the reversible seating (due to the movement of the seats) it has been assumed that the seats themselves might serve to provide a degree of division separating the front section of the vehicle from the central, wheelchair space section.

In virtual reality co-design workshops conducted with groups of women, a vehicle layout design was demonstrated with a central seating unit dividing the vehicle into two halves, each with 5 seats facing each other. This facing seating layout, while allowing for complete interior division, increased the potential for eye contact between passengers which made some women feel uncomfortable.

> "I think I prefer not to face people because then that's the least eye contact. Less eye contact means you feel slightly safer."

The design of the inclusive SAV seating layout, may address these feelings of discomfort by maximising the number of available forward facing seats and affording a degree of choice in seating position by using the reversible seating.



Whole-vehicle dividers: translucent divider and luggage rack above folding seating (left), reversible seating and luggage rack (right)

AT-SEAT DIVISION

As well as whole-vehicle division providing a general sense of separation between passengers in different parts of the vehicle, more localised at-seat division was also considered to be beneficial in improving security.

Participants discussed how armrests would provide suitable separation between passengers but suggested that they should be designed to fill the entire space between the armrest and the seat to reduce the potential for contact between adjacent passengers. Existing experiences of armrests in shared transport contexts raised concerns about the potential for conflict arising from shared armrests between seats.

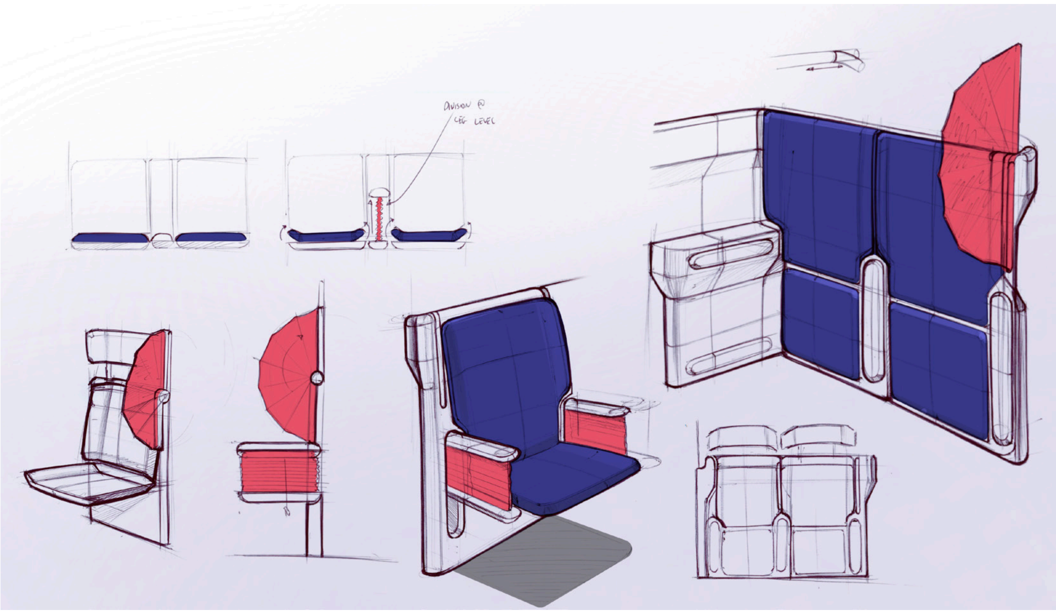
Head-height screens were also suggested to improve feelings of security by separating adjacent passengers and received positive feedback when tested by women in the VR vehicle. Participants stressed that these dividers should be retractable to allow for conversation when travelling with friends.

A fan shaped retractable divider with a folding armrest was presented to participants in the second focused workshops. This design was viewed positively by participants with one sharing:

> "[Being] separated from the other people. It helps, if it's complete strangers around you, to feel in your own space. There's other people facing you but they're pretty far and the ones super close you don't see so then there's no eye contact so maybe it's more comfortable."

One suggested improvement to this design in the second focused workshops was to extend the divider to meet the armrest, removing any open gaps between passengers. Participants also discussed the need for individual dividers for each seat to reduce any potential conflicts about their position between adjacent passengers, providing individuals with choice and control over their own security.

In the concept inclusive SAV interior, armrests and fixed dividers are used to separate the seating at either end of the vehicle with retractable textile dividers used to provide configurable, complete division between these seats. The folding seating does not incorporate the same degree of division due to the movement of these seats but the distance between these seats may serve to improve security by providing a degree of separation.



Selection of early at-seat division ideation sketches.

Retractable textile divider between seats at front and rear of vehicle.

Front and rear seat design with dividers and armrests

INTERIOR GUIDANCE & SUPPORT

For several visually and mobility impaired workshop participants, moving and navigating inside a vehicle presented challenges. Several suggestions were made for design interventions that might help these passengers to safely and easily move around onboard the vehicle by providing suitable guidance and support through physical features as well as the use of colour and texture.

GUIDERAIL AND GRAB HANDLES

A commonly suggested feature to aid visually impaired people in navigating the vehicle interior was a continuous guide rail that can be held by passengers, ensuring that they are guided within areas designated for movement and avoiding collision with any seating, luggage, or fellow passengers. Concepts for this rail system were created, seeking to provide visually impaired people with a continuous, unbroken rail that is immediately reachable on entry to the vehicle and can be followed to the passenger's seat. This would reduce the number of instances where a VI passenger needs to feel for handles, seats, and other features to navigate.

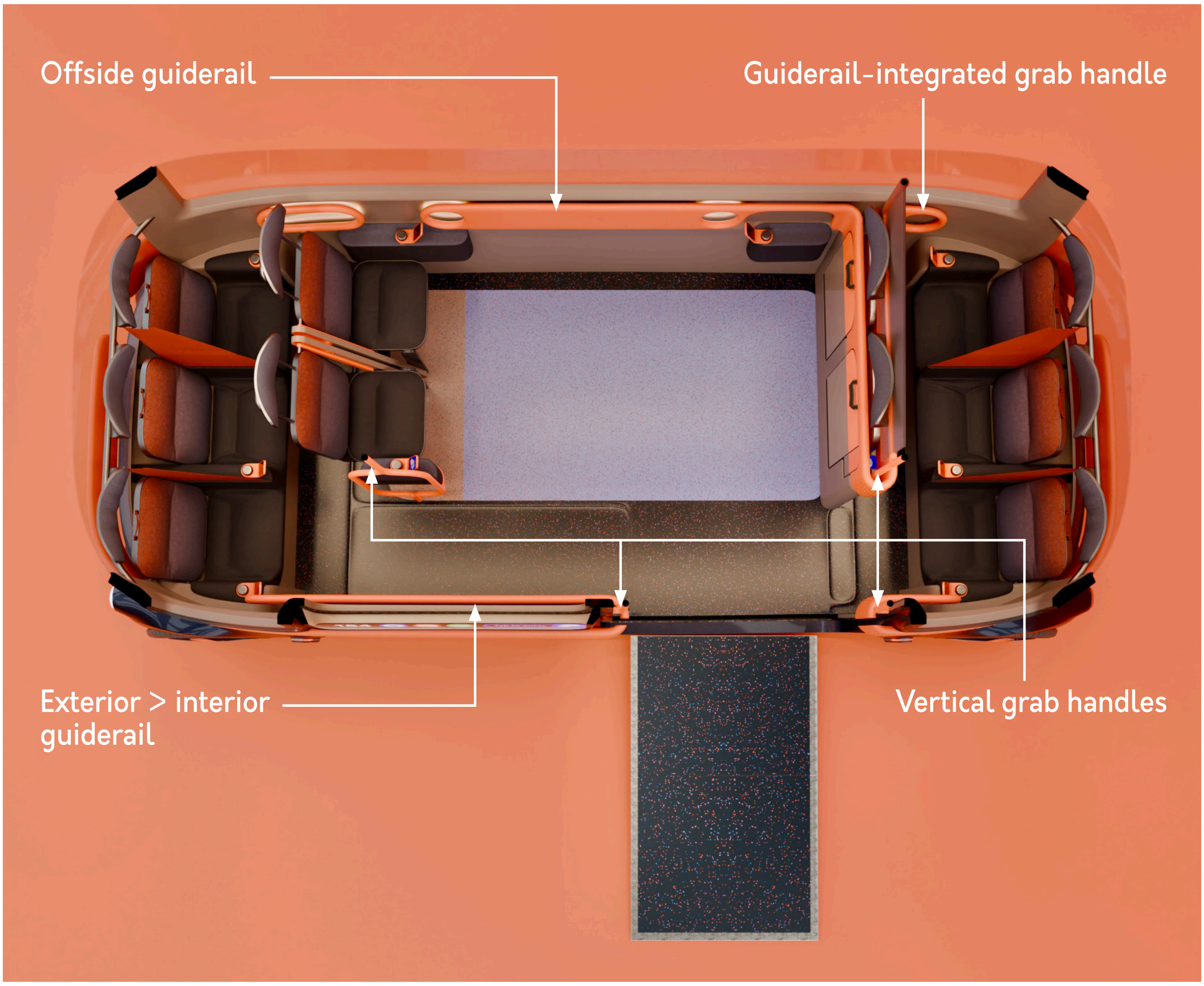
However, the reality of providing such a complete guide rail alongside other necessary elements of the interior layout is difficult. A guide rail positioned around the edge of the interior space, above the seat backs would require all seating to be foldable to prevent visually impaired people colliding with the seat pad while holding the rail, it would also require seating at either end of the vehicle to be positioned inboard of the wheelhouses to allow for open floor space to the side of the rail.

A rail positioned around the edge of the interior space, without the use of folding seating would require seats to be positioned in the centre of the vehicle with clear space around each edge reducing or removing the potential for an open wheelchair space and reducing the amount of interior space that can be used for seating. During the course of this PhD, the researcher was responsible for facilitating inclusive SAV design workshops with mobility design MA students. One of these groups of students, focusing on visual impairment, created an alternative concept for a guide rail in the centre of the vehicle, with seating around the edge, facing inwards. This concept presents perhaps the most efficient, fully continuous guide rail, but the absence of clear central floor space presents challenges for incorporation alongside other inclusive design opportunities e.g. wheelchair space and manoeuvring.

The guide rail concept was initially suggested by visually impaired participants, and was generally considered to be beneficial in navigating the vehicle when tested in focused workshops. Some VI people, however, suggested that vertical grab handles should also be incorporated into the vehicle design as these are more familiar from other vehicles. Vertical handles were also suggested by mobility impaired people to help steady themselves when moving inside the vehicle.

In the inclusive concept SAV interior, a guide rail follows from the door of the vehicle to the nearside front and rear seats. The rail transitions into a grab handle that indicates proximity to the seat and can be used to help mobility impaired people with sitting and standing, and visually impaired people with locating their seating position. As mentioned in previous discussions of layout, the relative ease of access to these seats could make them suitable to be designated as priority seats, reserved for use by disabled passengers.

Throughout the rest of the vehicle, other horizontal guide rails are located on the top of the fixed folding seating and along the off-side wall of the vehicle. Vertical grab handles are also placed at the doors and next to both sets of folding seating..



Interior layout showing locations of guide rails and handles

TACTILE SURFACE TEXTURES

While guide rails and handles allow visually impaired people to move and position themselves in the vehicle without collisions, certain details about the interior navigation cannot be intuitively understood by the presence of these features alone. Notably, guide rails do not give a sense of proximity or direction to vehicle touchpoints e.g. the vehicle door or seating. To help VI people understand their position relative to these features, tactile surfaces can be incorporated into the design of the guide rails and other interior surfaces.

During focused workshops with visually impaired people, a selection of 3D printed tactile surfaces were tested with participants to prompt discussions regarding this kind of tactile navigation. These surfaces were designed to represent a range of uses of tactile surfaces including radial textures which could be used to direct VI people to a touchpoint at the centre and textures designed to indicate a single direction.

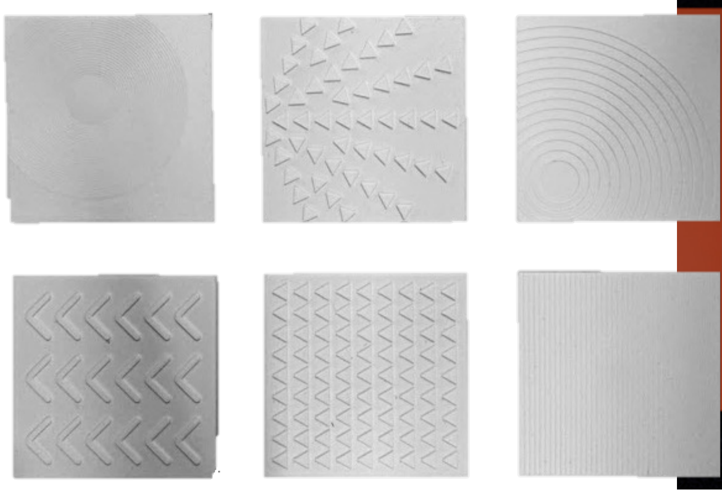
The range of samples created also used a variety of texture types including the overall shape of the surface (e.g. a circular recess), the shape of protrusions (e.g. triangular or chevron shaped to indicate direction), and the feeling of the texture determined by the shape of its profile (e.g. a sawtooth texture designed to feel smoother in one direction).

Participants discussed how obvious binary distinctions between smooth and rough surfaces were easy to recognise and could be used to indicate proximity to certain features e.g. the rail is rougher when closer to the door. Understanding direction from the samples provided, however, was more challenging with the ambiguous direction of triangular shaped protrusions, and the fine texture of the sawtooth ridges making both directions feel similar.

The texture that participants most favoured for communicating direction was chevron-shaped protrusions. These allowed participants to either feel the outside point of the chevron, or the interior angle to determine the direction. In designing these textures, however, it is important that the distance between adjacent chevrons is wider than a finger's width to ensure that these gaps are not misread as interior angles.

In the final inclusive SAV design, a repeating chevron texture is used to direct passengers from their seat to the doors of the vehicle and from the outside of the vehicle towards the door. The prominence of the chevron shaped protrusions gradually increases as they get closer to the door. Near the door, the chevrons are replaced with vertical straight lines to indicate proximity to the step or ramp.

Texture samples and chevron texture on SAV exterior guide rail



TACTILE FLOORING

Tactile floor surfaces are regularly used to communicate environmental information to visually impaired people through the feeling underfoot, or the use of a cane. Visually impaired participants discussed the need for tactile surfacing to indicate the location of the step off the vehicle and as a beneficial tool in navigating the interior space.

> "You could have a ridge around where the wheelchair is going to be, or something. So, you don't walk into it." -V1P1

As tactile paving surfaces are standardised to communicate specific functions to visually impaired people (Department for Transport, 2021), similar surfaces should be used to aid navigation inside the vehicle. For navigating a path, a series of raised, flat-topped bars oriented in the direction of the path are usually used. To replicate this style of surface, flat-topped ridges are used to line each edge of the inclusive SAV's main interior walkway up to a distance of ~300mm from the front of the seating- to account for passengers' legroom. For narrower passages between folding seats and fixed seats, these ridges converge into a single strip, positioned to avoid legroom of nearby passengers as best as possible. More prominent 'corduroy' ridges are used across the doorway to indicate the edge of the vehicle, as these are commonly used to indicate the proximity of steps.

As tactile floor surfaces can cause discomfort for wheelchair users, the central wheelchair section does not feature the same system of ridges but allows a clear, smooth route for manoeuvring.

COLOUR AND CONTRAST

Many visually impaired people rely on a degree of vision to help them navigate an interior space. During workshops, visually impaired people suggested that bright, contrasting colours should be used to indicate the location of different interior components.

When discussing folding seating concepts, visually impaired people suggested that contrasting colours could be used on different parts of the seat to make it clear if the seat is folded up or down. The design of fixed folding seating that integrates with the vehicle interior surfaces discussed above, already allows for this with contrasting colours for the seat upholstery and underside. As the design for reversible seating requires seat upholstery to always be visible, this same contrast cannot be used to indicate the status of these seats. Instead, the inside of the seat lever is given a contrasting colour which is visible from the side when folded down.

The overall design of the inclusive SAV, seeks to intuitively indicate the location and functionality of all vehicle features through use of colour and contrast by categorising components and features and giving distinctive, contrasting colours to indicate their use. Particular examples of this can be seen in the use of an orange highlight colour for all guide rails and grab handles, contrasting wall and floor colours, and three colours indicating different zones of the floor layout (blue - wheelchair space, grey - luggage/ reversible seating space, navy - general moving space).

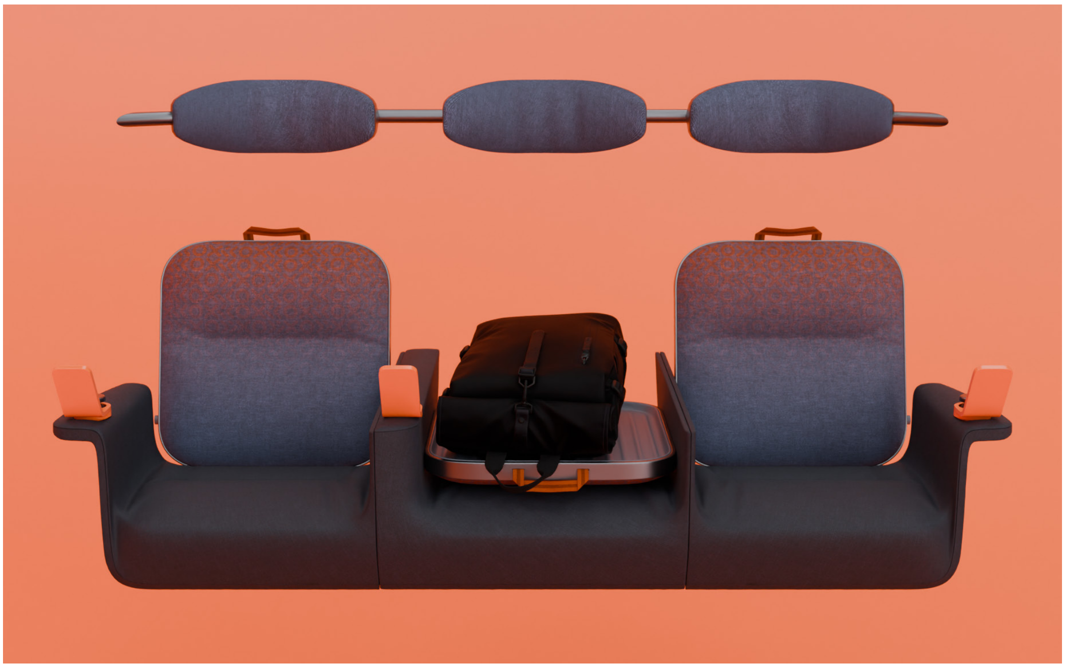
INTERIOR STORAGE & LUGGAGE

While luggage storage is a general need for passengers in any vehicle, excluded groups have specific requirements for storage spaces that can store specific assistive devices/ accommodate assistance dogs, are accessible, close by- for security, and non-obstructive.

To discourage misuse of wheelchair spaces as luggage storage - a common experience in public transport services - the inclusive SAV design provides overhead luggage storage above the seats at each end of the vehicle.

As overhead luggage storage is not accessible to those with disabilities impacting their strength and reach, additional floor-level space may be used including: space in front of the armrests of the 4 corner seats - also considered a suitable additional space for assistance dogs, space underneath the fixed folding seating (if occupied when no wheelchair user is onboard), the space underneath the reversible seating (if occupied) and the space in front and behind the reversible seating (if in the folded position). These luggage locations provide nearby, mid-sized luggage storage for 8 out of 10 seats, addressing the needs of some women and visually impaired workshop participants to keep their personal belongings nearby to avoid theft. Other unused space such as that found to the side of the corner seats' armrests may also provide secure, nearby storage in positions where VI people can maintain contact with their belongings.

As passenger preferences for forward facing travel could result in lower utilisation of the front row of rear-facing seats, the inclusive SAV design also allows for these seats to fold down into additional, low-level luggage spaces.



Front/rear folding seat luggage rack.

Overhead luggage rack above reversible seating.

EXTERIOR DESIGN

The following section includes concepts for more inclusive SAV exterior design in the areas of:

- Exterior guidance and support for visually and mobility impaired people
- Accessible boarding for wheelchair users and other mobility impaired people

While the exterior of the vehicle is only responsible for a very small part of a passenger's journey experience, there are a few inclusive design considerations that may impact the design of the exterior. While many of the interior and SAV platform-related elements discussed above inevitably impact the design of the exterior (e.g. door positioning), these design decisions do not directly addressing an issue of exclusion through the design of the exterior and are, therefore, not detailed in this section. Instead, considerations related to the boarding of the SAV provide the focus of this section.

INCLUSIVE DESIGN CONSIDERATIONS

Make the location of vehicle doors, steps, ramps, and buttons obvious to visually impaired people

Provide means of physical support for disabled people when boarding

Guide visually impaired people towards and through vehicle doors

Provide ramps, lifts, or steps to ensure ease of boarding in multiple scenarios- including from kerb & road levels

Allow automatic deployment of ramp/ lift access for wheelchair users

Reliable operation of ramps and lifts to reduce delays and diversions for wheelchair users

EXTERIOR GUIDANCE & SUPPORT

As with navigating the interior of the vehicle, visually impaired people can have difficulty navigating from the outside of the vehicle to the doors. Guidance and support features can help visually impaired people and mobility impaired people to board the vehicle.

In the inclusive SAV design, guidance to the door is provided by extending the interior guide rail to the outside of the vehicle. Continuing the rail and textures along the length of the vehicle allows people to approach the side of the vehicle from any point and locate the rail. Visually impaired participants in focused workshops discussed that the broadly symmetrical nature of the vehicle would make it challenging to identify the direction of the door, suggesting contrasting left and right textures could be used to achieve this. As contrasting textures would need to be learnt and remembered by VI people, more intuitive directional textures as used inside the vehicle, have also been incorporated into the design of the exterior railing to aid learnability. The guide rail has also been designed with additional depth (compared to cylindrical railings) and a bright contrasting colour to aid visibility of the rail and give a distinctive graphical design to the vehicle exterior which might be more easily recognised by visually impaired people.

A sliding door reduces the risk of collisions with waiting passengers by safely tucking the door behind the handrail. Suitable clearance is incorporated between the rail and the door so a VI passenger could locate the rail of a stopped vehicle before the door is open. This would be particularly relevant in spontaneous access scenarios where a passenger may be required to interact with external interfaces to access a stopped vehicle.

Vertical handles have also been incorporated into the exterior design by the door, providing physical support for mobility impaired people when stepping into the vehicle.

Vehicle exterior showing
handles and guide rails.

ACCESSIBLE BOARDING

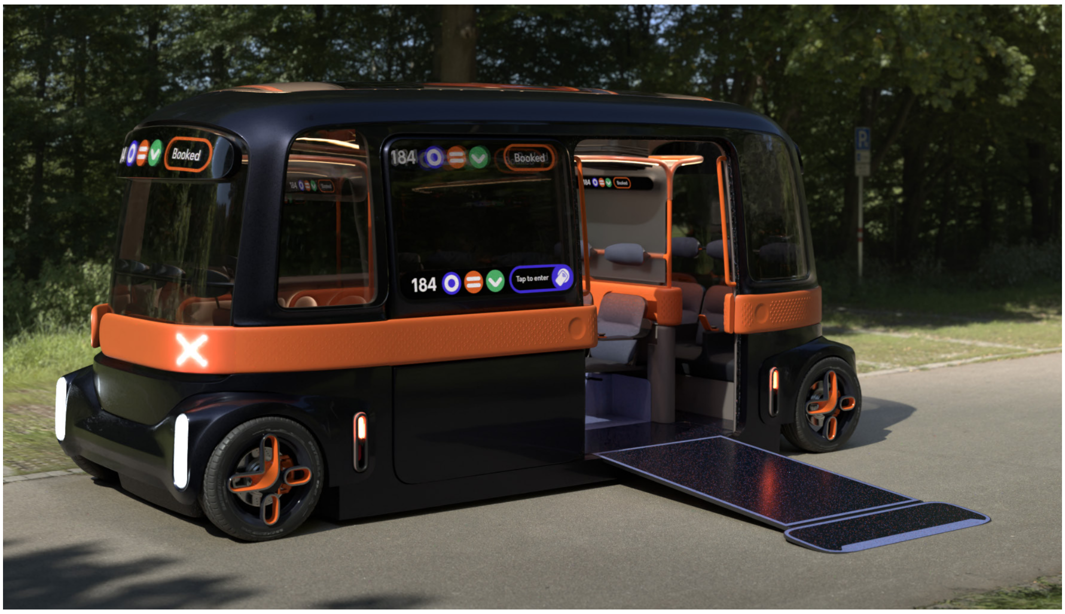
To aid disabled people in boarding the SAV, a retractable ramp and kneeling suspension system has been incorporated into the exterior design- as discussed in the SAV platform design section above.

This ramp is designed in two parts to allow for a shorter ramp to be deployed to kerb height - operated each time the vehicle stops, and a longer ramp which can be used where boarding from ground-level is required by a wheelchair user.

The short section of the ramp is designed to be stowed on the outside of the vehicle and to utilise a simple, fold-down operation. This method of deployment is intended to reduce the risk of failure that more complex systems might create and to allow for a fail-operational manual deployment where an emergency override switch can release the ramp and allow it to drop into place. Such a system would enable wheelchair users to always exit the vehicle at their stop, and avoid the current difficulties they experience where faulty ramps require them to be diverted to a transport hub to exit the vehicle.

The longer section of ramp is stowed beneath the vehicle floor and slides out in a similar fashion to other transport service vehicle ramps.

The use of a ramp instead of a lift- as used in some SAV designs- could serve to reduce the stigmatising impacts of long, complex boarding processes where wheelchair users can sometimes feel embarrassed about delaying other passengers. The deployment of the short section of the ramp at each stop may also serve to reduce this stigma as it forms part of the standard boarding process, allowing all passengers to benefit from a step-free boarding experience e.g. improving ease of access for those with wheeled luggage or pushchairs.



Longer wheelchair ramp to ground-level.

Short wheelchair ramp and
door opening sequence.

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