Scientific Foundation SPIROSKI, Skopje, Republic of Macedonia
South East European Journal of Architecture and Design
Volume 2022; Article ID 10063, 8 pages
http://doi.org/10.3889/seejad.2022.10063
Design

OPEN ACCESS

Application of Virtual Ergonomic Tools for Evaluating an Inclusive Autonomous Vehicle Interior

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Citation: Angeleska E, Sidorenko S, Jankovic A, Rizov T. Application of Virtual Ergonomic Tools for Evaluating an Inclusive Autonomous Vehicle Interior. SEE J Archit Des. 2022 Mar 14; 2022:10063. https://doi.org/10.3889/seejad.2022.10063

Key words: Virtual ergonomics; Inclusive design; Autonomous vehicles.

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Received: 14-Apr-2022; **Revised:** 27-Apr-2022; **Accepted:** 28-Apr-2022; **Published:** 30-Apr-2022

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Competing Interests: The author have declared that no competing interests exist.

Abstract

Autonomous vehicles (AVs) present the opportunity to increase the passengers' comfort during the rides and help persons with impairments make daily transportation independently. However, in order to make full use of these advantages, a new design approach is needed for developing AV models. This paper aims to present a spe-cific approach in the design process and ergonomic evaluation of an inclusive AV interior. The used approach of combining vehicle standards and regulations, ergo-nomic and anthropometric data, with user requirements, inclusive principles and universal design is explained in detail. In addition, virtual ergonomic evaluations are conducted in order to examine the success of applying the ergonomic and inclusive approach. The results emphasize the bene-fits of virtual ergonomic tools for successful ergonomic assessments.

Introduction

The vehicle interior is a complex system consisting of several subsystems such as – the seating system, safety system, infotainment system etc. All these subsystems are composed of other subsystems at different levels. For example, the seating system has the seat, backrest, headrest, armrests, but also the suspension subsystem and roller slides. In order to provide maximum comfort and safety for the passengers, the ergonomic features of all the vehicle interior subsystems need to be considered separately, and then as an interconnected whole. In that sense, safe and comfort can be achieved through: proper sizing and placement of the seats; optimal placement of the control components and other elements so that they are within comfortable reach zones; adequate shaping of the door opening; offering options for adjustments; offering additional comfort features; etc. More precisely, vehicle ergonomics involves "fitting" the components to the potential users, or designing the interior in a way that allows users to fit in the space and use the provided equipment without discomfort or operating errors [1].

Occupant packaging and ergonomics is an extremely important matter that dictates the percentage of population that will be able to fit in the vehicle with sufficient body clearance. The modern user-centred vehicle design approach is called "inside-out" meaning the primary focus is on the occupants' needs and issues which help shape the interior volume and the exterior characteristics come as a result of this process [2]. Ergonomists who are a part of the formal design process use such approaches in order to bring ergonomic issues to the attention of other involved disciplines. They rely on the following methods and tools [2]: application of standards, guidelines and regulations (such as SAE standards relevant to occupant packaging [3], [4], [5]); considering static anthropometric measurements of human body dimensions needed for sizing the space and components [6]; using 2-dimensional manikins and 2-dimensional package drawings for a simplistic examination of the designed space [7]; using computer-aided-design (CAD) systems for more valid virtual ergonomic simulations [8]; and finally, development of mock-ups, fitting trails, and user trails for an in-depth evaluation which happens in the more advanced design stages and requires more costs.

These methods and tools are based on a

wide range of interdisciplinary information and their practical application can be daunting, especially for designers that often lack expertise in the technical fields. Therefore, the need for establishing a new "design tool" based on human-centric principles which facilitates the vehicle design process was noticed. Previous work was focused on developing such a "tool" as an IT model, or more precisely, a design platform consisted of databases containing systematized information, recommendations and principles from all relevant interdisciplinary fields that should be included in the vehicle design process. The strength of this platform is in the practical representation of all the information that is used as an input in the design and development process. The difference between the platform and other similar platforms based on system models is in the focus on human-centric aspects and ergonomic and inclusive principles.

This paper presents the experimental stage of using the platform with the goal of designing an ergonomic and inclusive interior for an accessible AV shared-ride-shuttle. In order to prove the success of using the data provided by the platform, a virtual ergonomic tool is used for evaluating the comfort of the designed AV.

The application of CAD systems and virtual ergonomic software offers the benefit of experimenting with the design in the earliest phases without additional costs, as well as performing corrective measures and adjustments according to the accommodation and analysis of virtual manikins from various percentiles in the designed vehicle.

Autonomous vehicles and inclusion

Fully autonomous vehicles (AVs) are vehicles with a level 5 automation (according to SAE Internationals' standard J3016TM "Levels of Driving Automation" [9]) which have automated driving features that do not require a person to participate as a driver. Such vehicles are able to perform all driving tasks independently under all conditions due to their equipment with modern technological devices – sensors, controllers, computers, actuators, algorithms, and advanced software [10]. AVs have the potential to change our way of life, the way we use transportation and the urban environments as they offer "the opportunity for safe, efficient, accessible and affordable transportation" [11]. Multiple sources emphasize the benefits of the commercial use of self-driving cars among which the most crucial are: lower CO_2 emissions; optimized fuel consumption; lower traffic congestion; increasing traffic safety by eliminating human factors of driving associated with accidents such as sleepiness, anger, distraction or intoxication; and very importantly, helping the elderly and disabled live independently [11], [12], [13], [14].

The interest of vulnerable road users in autonomous vehicles

Vulnerable road users, such as persons with impairments and the elderly, face significant difficulties while attempting to use public or private transportation. These issues include obstacles in the urban environment and inaccessible transportation modes. Multiple international researches confirm the dissatisfaction these individuals have with the current available transportation options [15], [16].

In order to collect the opinions concerning this topic of persons with impairments in the country, an online survey was conducted involving 70 participants with different types of impairments (mobility, vision, hearing). The answers showed a strong annoyance with public transportation and an interest in alternative transportation solutions that can offer a greater level of independence. For example, the bus was chosen as most commonly used public transportation. However, this transportation mode received a low-grade regarding usability and comfort of travel (Figure 1). In addition, the respondents stated that the possibility of independent travel is extremely important to them, that they feel independent travel would improve their life significantly (Figure 2) and that they are interested in the possibilities of AVs (Figure 3).

These answers indicate that vulnerable road users around the world are likely to benefit most from self-driving vehicles. This is why "disability has been a leitmotif of the discourse of AVs" [17].

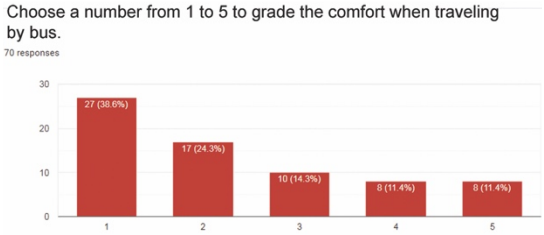


Figure 1: Survey responses of persons with disabilities regarding the comfort of using a bus

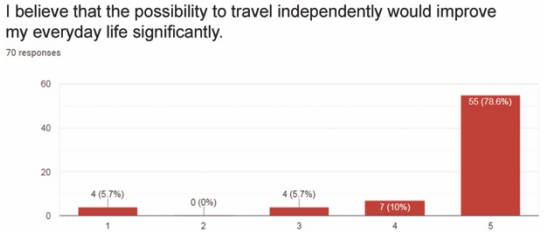


Figure 2: Survey responses of persons with disabilities regarding the importance of independent travel

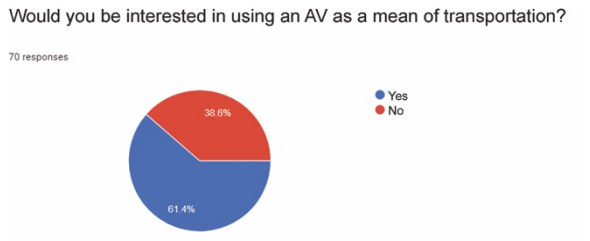


Figure 3: Survey responses of persons with disabilities regarding the interest in using an AV

Accessibility approach

Accessibility principles have already been considered and applied in the development of standard vehicle models in order to provide possibilities of accommodation or even independent travel for persons with impairments. Structural and body modifications are not a novel concept and are done in order to: offer alternative options for the vehicle-operating-controls; stow mobility-aid devices; fit persons with a wheelchair or scooter; offer alternative ingress/egress methods for easier transfer without lifting etc. The most common additional features include seat lifts, wheelchair lifts, stowing solutions, driving aids, wheelchair tie-downs and occupant restraint systems, side and back ramps etc. [18]. However, for persons with a higher severity level of impairments, the possibilities of using a modified vehicle model are very limited. This is where the benefit of AVs becomes obvious.

Disability is commonly referred to as a “social phenomenon appearing as a result of obstacles and limitations in the environment”, meaning that it is a result of poor design [19]. In order to properly design new vehicle models and make full use of the benefits AVs can offer for persons with impairments it is important to analyse their needs, use ergonomic and anthropometric data, include rapidly advancing technological features, and rely on universal design principles in the development process. Through universal design a product can provide adaptation and flexibility in use [20] and remove possible usability barriers.

Designing an inclusive autonomous vehicle interior

With the goal to explore the practical application of the platform containing ergonomic and inclusive principles for the AV development, and provide an example of how the design approach needs to adjust to the possibilities of a complete interior redefinition AV models present, an AV interior was designed and used as a design case study.

The designed AV interior was mostly based on information in the databases related with vehicle design and ergonomics [1], [2], [21], anthropometric measurements including data of persons with mobility impairments using moving-aid devices [22], [23], existing recommendations for developing inclusive AV models [16], [24], as well as the experiences and requirements of persons with impairments gathered through a questionnaire.

The drawn conclusions and their systematization in the form of guidelines to be followed as minimum design requirements for developing ergonomic and inclusive AV interiors [25] were incorporated in separate databases of the design platform. The guidelines for proper dimensioning of the vehicle space and all included components, as well as the recommendations for the UI were followed for developing a 3D CAD model of an autonomous shuttle interior. In addition, the needs of persons with disabilities were taken into consideration. These were gathered through the previously mentioned survey and helped to gain an insight into particular transportation difficulties persons with impairments face and withdraw conclusions for possible solutions. The difficulties were categorized in 3 main categories and the conclusions for possible solutions (or user requirements) were listed as additional design guidelines (Table 1).

Table 1: Survey responses of persons with disabilities regarding difficulties with transportation they face and conclusions listed as possible solutions

Difficulty	Solutions
Ingress/egress	Side electric ramp Additional handles near the doors Wider door openings Sliding doors Lower floor
Accommodation	Wide interior space Free space in the leg and feet zone More space between seats Folding seats Luggage space for storing aid-devices Systems for safety fastening
Identification	Ergonomic placement of UI screens Inclusive UI graphics Multimodal UI

After taking into consideration all recommendations, the main characteristics for the AV were defined prior to the design process. Firstly, the type of AV was defined and its’ main dimensions. Next, the seat positions and their movement was defined. The following step was defining the characteristics of all elements related with the ingress/egress process. At the end, the reach zones were considered to define the placement of interior components and all other details.

The decision was to design an AV shuttle for shared rides with 4 foldable seats designed

ergonomically which have a folding backrest and slide toward the back to liberate space for accommodating a person in a wheelchair or power scooter. Other selected design elements are:

Interior dimensions – The interior dimensions were chosen as 3650x1780mm to allow free space for free entering and moving/turning of persons using a mobility-aid device.

Door size – The dimensions of the door were chosen as 915x1400mm, the door was designed with a rectangular shape and sliding to the side. The main goal with this choice was to provide sufficient space for ingress/egress. An additional fold-out floor ramp (760x132mm, 10°) was also planned for facilitating the ingress/egress process.

User interface - It was decided to include screens for the UI and place them in the defined most comfortable reach and viewing zones of the occupants. An additional large screen was considered for displaying all the information in a larger scale.

Comfort and safety features – Fastening systems, armrests and storage space were also planned as additional features.

The final result of the designed AV are presented on the following images (Figure 4, Figure 5, Figure 6, and Figure 7).

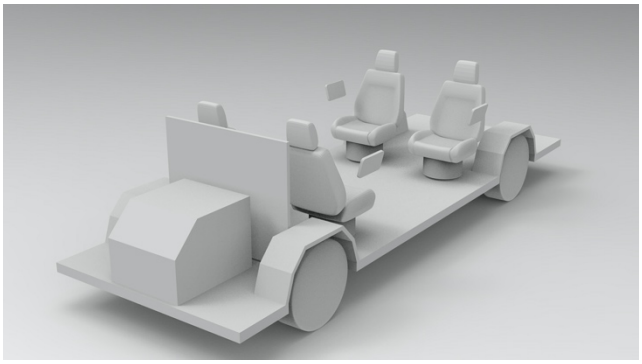


Figure 4: Beginning stages of designing the AV interior – defining the interior dimensions, seat, and screen placement

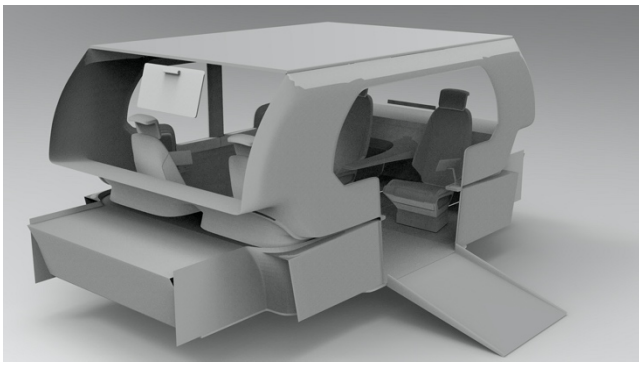


Figure 5: Defining the interior volume, side door and ramp

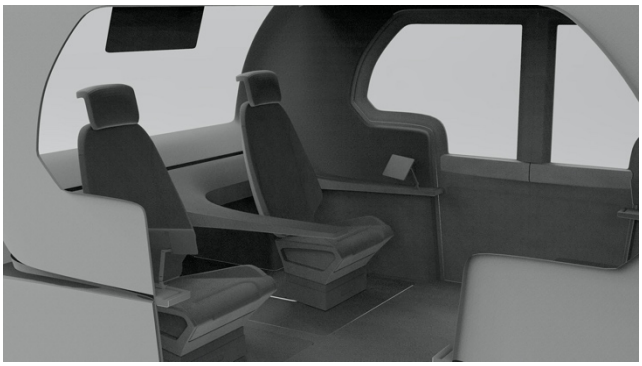


Figure 6: Close-up of the designed ergonomic seats, armrests and UI screen placement

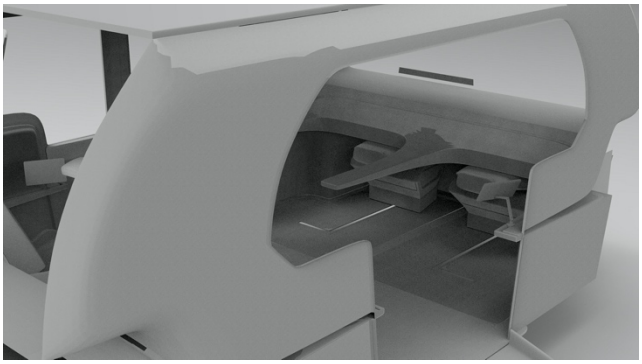


Figure 7: Close-up of the seats folded and stored in the back for liberating space to accommodate a wheelchair user

Ergonomic evaluations

Virtual ergonomic tools are very beneficial for evaluating the comfort and safety features of the designed products. The beginnings of using digital humans for testing the ergonomics of vehicle models were mostly related with the drivers' workstation and included human models that represented basic 3-dimensional body dimensions [26]. Later on, these models were based on laboratory data in order to simulate realistic body positions and begun to be applied for defining reach zones for positioning controls [26]. Nowadays, the use of virtual environment systems and human building modules, even augmented reality prototypes, are an inevitable approach in the vehicle human factors and ergonomics evaluation helping to define occupant envelopes, reach zones, view fields, comfortable body positions etc. [8], [27].

For the purpose of this study, the software Siemens Jack Human Simulator was used to conduct virtual ergonomic evaluations of the inclusive AV interior.

Jack is a software offering a base of digital objects and human models from different percentiles and allowing an interaction with those models in a graphical environment [28]. The software allows a visualization of various design concepts that can be easily imported in the virtual world. Then, for those design concepts a wide range of ergonomic tests can be done and reports can be generated. The most important feature is that the software offers the use of manikins with real biomechanical, anthropometric and ergonomic characteristics. The manikins can be studied in the virtual environment and by doing so the human factors in the design can be analysed with the goal to evaluate the safety, efficiency and comfort of the designed product. The manikins in Jack behave like real people – they have balance and strength, they are able to move, they have complex body joints that can be manually manipulated.

Jacks' special module Occupant Packaging Toolkit (OPT) is commonly used to optimize the vehicle design and achieve maximum ergonomics for the driver and passenger [29]. This module offers a set of valuable tools among which are the SAE Packaging Guidelines, Comfort Assessment, Vision Analysis Tool etc. The application of these tools for the analysis of the designed AV is elaborated in this section.

The virtual ergonomic evaluation was done by inserting the designed AV CAD model in the Jack simulation environment as an STL file and loading male and female manikins from the 50th percentile.

The first goal was to test if the designed vehicle was sized properly and can accommodate the passengers comfortably. The male manikin was placed in several positions simulating an ingress situation and it was concluded that the door width and height are sized appropriately, the manikin was able to pass through the door opening with minimal back and neck bending (Figure 8).

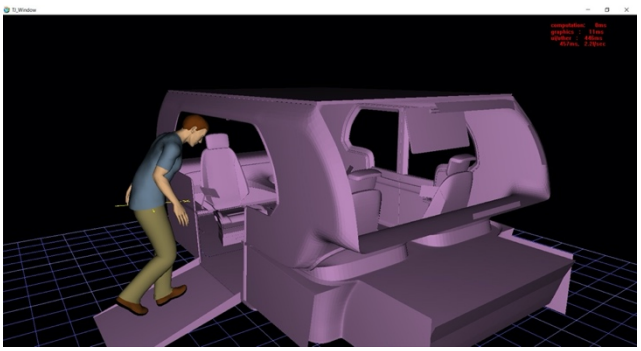


Figure 8: Examining the ingress with a 50th percentile male manikin

Next, the sizing and placement of the seats was evaluated by placing the manikin in a seated position which revealed no issues (Figure 9).

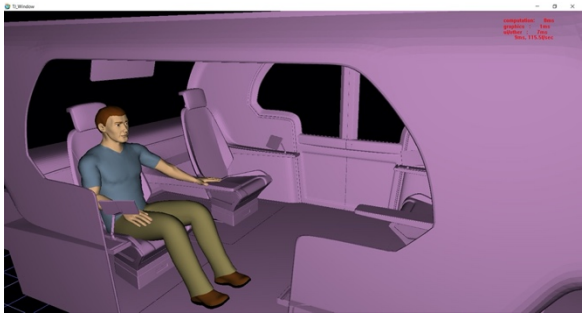


Figure 9: Examining the comfort of sitting with a 50th percentile male manikin

The manikin was then placed with one hand on the armrest and the other on the tablet in order to examine if the components are placed within comfortable reach zones of the passengers (Figure 10). This position of the manikin seemed natural as well.

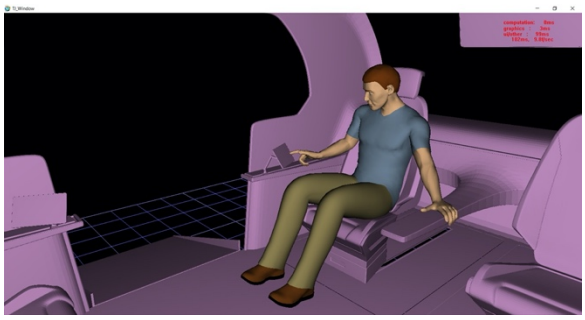


Figure 10: Examining the placement of the control screen using a 50th percentile male manikin

However, additional comfort evaluations were done using Jacks' analysis modules. Firstly, using the Occupant Packaging Toolkit and Comfort Assessment Tool the comfort of all body parts and joints of the virtual manikins (passengers) was evaluated. The graphical representation of the results contained only green bars meaning that in a seated position there were no comfort issues detected, the values were in the optimal range and no corrective measurements needed to be made (Figure 11).

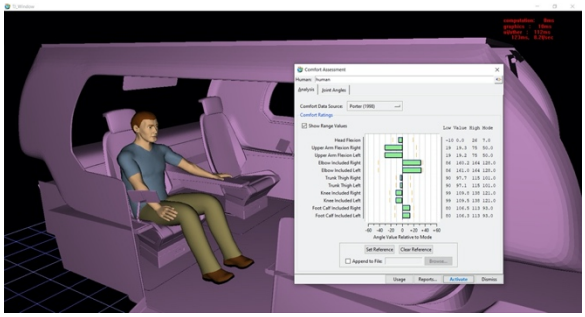


Figure 11: Examining the comfort of all body parts in a seated position using a 50th percentile male manikin (method: Occupant Packaging Toolkit – Comfort Assessment Tool)

Next, using the Occupant Packaging Toolkit and SAE Packaging Guidelines the passengers' head clearance was checked. The graphical result of this tool showed there is more than sufficient head clearance for the passengers (Figure 12).

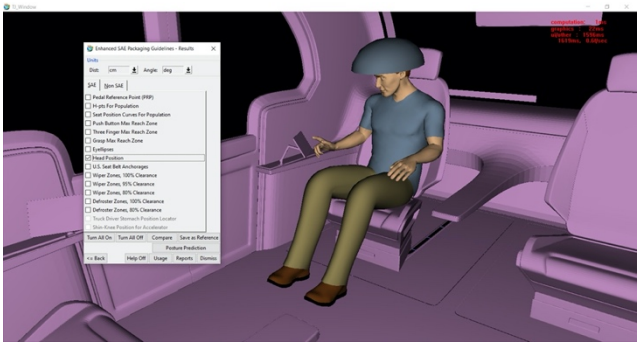


Figure 12: Examining the head clearance in a seated position using a 50th percentile male manikin (method: Occupant Packaging Toolkit – SAE Packaging Guidelines)

Using the same method, the comfortable reach zones for controls were studied. The graphical results showed that the control device was placed within comfortable reach zones (Figure 13).

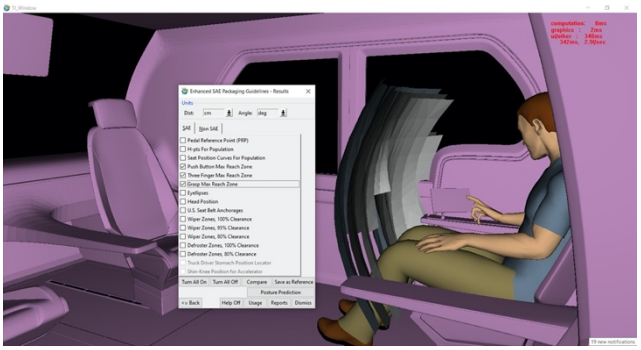


Figure 13: Examining the comfortable reach zones in a seated position using a 50th percentile male manikin (method: Occupant Packaging Toolkit – SAE Packaging Guidelines)

In addition, it was checked if the device is placed within the minimum reach zones and it was confirmed that the touch screen is within the minimum reach zone (Figure 14).

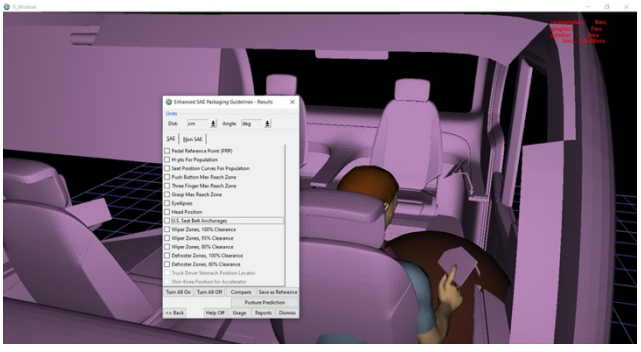


Figure 14: Examining the minimum reach zones in a seated position using a 50th percentile male manikin (method: Occupant Packaging Toolkit – SAE Packaging Guidelines)

The finger reach of both hands was checked as well, again showing everything is placed within the passengers' comfortable reach (Figure 15).

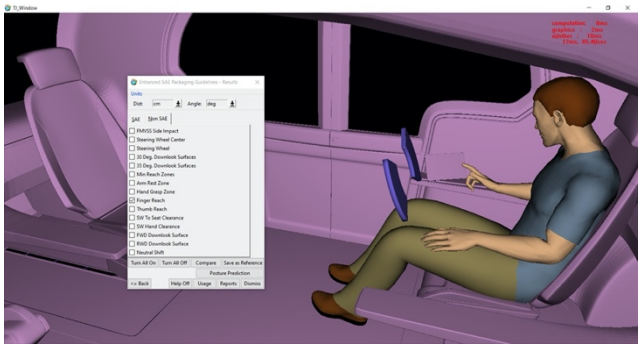


Figure 15: Examining the finger reach in a seated position using a 50th percentile male manikin (method: Occupant Packaging Toolkit – SAE Packaging Guidelines)

In order to evaluate the inclusiveness of the designed AV model a virtual manikin in a wheelchair was placed in the simulation environment. The ingress positions of the virtual manikin with a "mobility impairment" were analysed and it was evident that the designed ramp and entry space are accessible for wheelchair users (Figure 16).

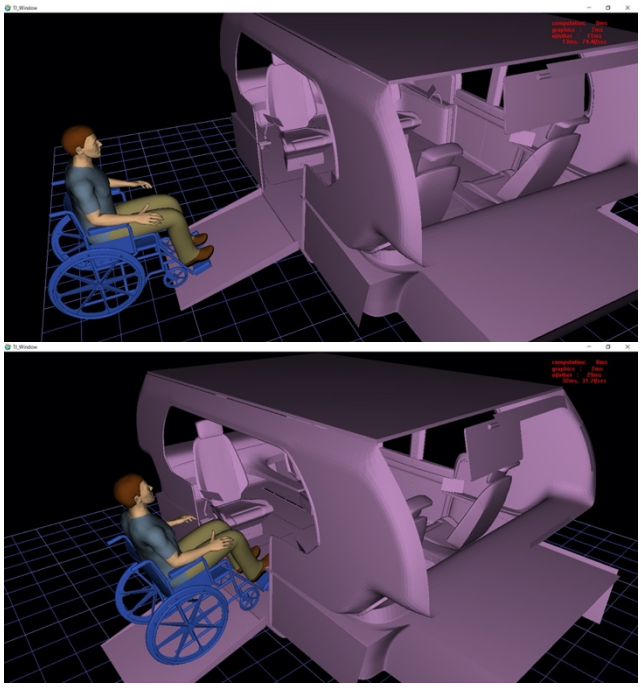


Figure 16: Examining the ingress with a 50th percentile male manikin in a wheelchair

The wheelchair manikin was also positioned in the cabins' passenger position where the standard seat was folded and stored in the back. The position of the manikin in the wheelchair appeared natural (Figure 17).

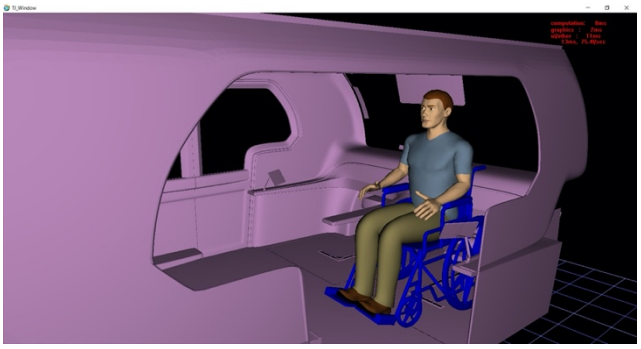


Figure 17: Examining the accommodation of a 50th percentile male manikin in a wheelchair

The vehicle was also examined with several manikins to simulate a sharing ride situation and see if there is sufficient personal space for the passengers, which also showed a positive result (Figure 18).

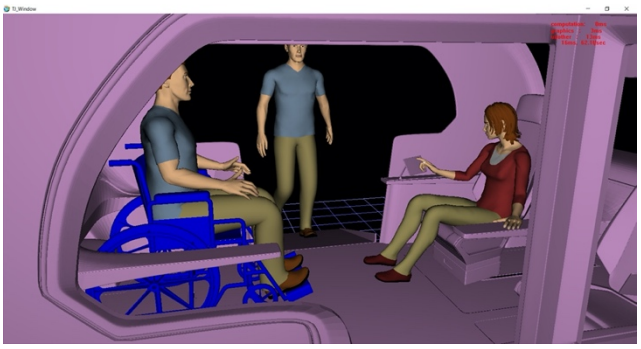


Figure 18: Examining the personal space for passengers in the AV interior using 50th percentile male and female manikins

Conclusion

This paper presents the design and evaluation process for an AV model developed to explore the practical application of an AV design platform in order to provide the possibility of equal transportation accessibility and independent travel for all users that the modern vehicle models can offer.

What can be concluded from the conducted evaluation is that the AV interior was successfully designed as both ergonomic and inclusive. The manipulations of the manikins in the virtual environment and the application of various analysis tools available in Jack revealed no issues or mistakes in the dimensioning of the AV or in the placement of the interior components. This indicates that using the platform for following the provided standards, ergonomic and anthropometric recommendations and combining them with the defined user requirements, inclusive principles and universal design resulted with a human-centric design of a vehicle that can provide equal accessibility for all potential users, including persons with impairments.

By this process, the importance of using all technological advancements for developing products that improve the quality of life of vulnerable society categories is highlighted. Inclusive AV models could help persons with impairments become more actively involved in all social activities. It is hoped that designers will use one segment of the proposed approach in the development of novel vehicle models.

Moreover, this paper emphasizes the benefits of applying virtual ergonomics in the early stages of the design process. Placing the virtual manikins in the designed space and having them interact with the designed components can easily reveal product flaws which should be instantly corrected before proceeding with further development. The advantage is that when the stage of building full size prototypes arrives, the designers can be certain there will be no, or only a few, further modifications necessary to provide maximum ergonomics for the users.

Acknowledgement

The authors thank the Virtual Vehicle Research GmbH in Graz, Austria for funding the PhD project of Elena Angeleska which this research is a part of.

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