

# AUTOMATED 3D CABIN GENERATION WITH PAXELERATE AND BLENDER USING THE CPACS FILE FORMAT

M. Engelmann<sup>1</sup>, D. Drust and M. Hornung  
Bauhaus Luftfahrt e.V.

Willy-Messerschmitt-Straße 1, 82024 Taufkirchen, Deutschland

## Abstract

The cabin is a crucial aspect of today's and future aircraft as it is the single most important element passengers are in contact with during a flight. It is thus increasingly important to get an in-depth impression of the layout, even during early design phases. However, in the current preliminary aircraft design process, 2D methods and cabin representations are common. This paper introduces a novel fast way to assess and visualize a cabin by displaying it in three dimensions. This enables a deeper understanding of a cabin during the early design phases by providing advanced assessment possibilities as well as visualization capabilities for photorealistic renders, animations and VR experiences.




The foundation for the model is the cabin and fuselage design environment (CAFE) of PAXelerate. In combination with the CPACS support, it enables a swift and easy cabin design process. With the help of the open source 3D creation suite Blender, the 2D cabin layout is translated into a detailed 3D cabin and fuselage geometry, which can then be further used for high quality renderings and cabin geometry post processing. This includes 3D object collision detection, the verification of safety zone and evacuation area sizing as well as a cabin volume calculation.

This rapid automated 3D cabin generation tool enables new possibilities for the cabin design during the preliminary aircraft design process by adding a third dimension and by providing an easy and fast way for photorealistic cabin renderings, VR experiences and a cabin assessment not possible using 2D methods. By using this approach, novel cabin concepts can thus be experienced from a completely different angle, benefiting both passengers and manufacturers of future aircraft.

## Keywords

Blender, CPACS, Cabin, Automation, Visualization

## Abbreviations

BHL	Bauhaus Luftfahrt e.V.		CPACS logo [1], representing CPACS files
AVACON	Advanced Aircraft Concepts LuFo research project		Blender logo [2], representing modules executed within Blender
ARB	AVACON research baseline aircraft		CAFE logo, representing modules executed within CAFE
CPACS	Common Parametric Aircraft Configuration Schema	API	Application Programming Interface
PAXelerate	BHL boarding simulation	CAFE	Cabin and fuselage design environment
VR	Virtual Reality	AR	Augmented Reality

## 1. MOTIVATION

In current and future aircraft, the cabin is a key aspect and the single most important element passengers

get in contact with during a flight. It is thus increasingly important to get an in-depth impression of the cabin layout, preferably already during the early phases of the design process. However, in the current

<sup>1</sup> Email: [marc.engelmann@bauhaus-luftfahrt.net](mailto:marc.engelmann@bauhaus-luftfahrt.net), Phone: +49 89 307 4849 55

preliminary aircraft design process, 2D methods and cabin representations are the norm.

At Bauhaus Luftfahrt (BHL), the cabin and fuselage creation process uses 2D design tools and the CPACS file format containing detailed aircraft model data. Furthermore, the passenger simulations for boarding and de-boarding scenarios are based on 2D methods as well. There is an increasing demand for an early 3D cabin impression during the early aircraft design phase and a demand for high quality, 3D cabin geometry for use in renderings or for an enhanced cabin geometry assessment not possible using 2D methods. However, there is currently no easy and fast way to satisfy this demand.

This paper thus introduces a novel concept to transition the existing CPACS geometry information into a rich 3D cabin geometry model. The use of a high degree of automation and the backwards compatibility with existing CPACS cabin files is of mayor importance. The geometry itself is used for high quality renderings with minimal manual effort as well as an enhanced 3D geometry assessment. Furthermore, the path for a transition to augmented reality (AR) or virtual reality (VR) experiences is provided.

## 2. TOOL OVERVIEW

This chapter contains a list of tools used for the method introduced in this paper as well as for its application. This contains PAXelerate and in particular the cabin and fuselage module called CAFE, the CPACS file format as well as the open source 3D creation suite Blender.

### 2.1. PAXelerate and CAFE

PAXelerate is an open source boarding simulation framework created by Bauhaus Luftfahrt [3]. The initial purpose as a fast and easy way to assess passenger flows during boarding processes has since been extended by a detailed cabin and fuselage design module called CAFE (“Cabin And Fuselage Environment”). In a recent step, an interface for the CPACS data format has been integrated, enabling a swift and interdisciplinary data exchange and providing easy import and export capabilities to a variety of different tools [4].

As this CAFE module within PAXelerate has evolved beyond its application scenarios for the boarding simulation, the transition into a standalone tool for fuselage and cabin design is the next logical step.

CAFE enables a sophisticated cabin and fuselage design by enabling a highly automated cabin design with very little input, such as the seat abreast and the number of passengers per class. The design of cabin layouts can be assessed concerning its CS-25 regulation conformity as well as concerning its CG and mass properties.

A representation of the user interface can be seen in Figure 1. Additional to the automated cabin layout generation, a manual creation using drag and drop or other input methods is possible as well. This also includes the import of existing CPACS files, which can then be modified within CAFE. Lastly, all layouts and fuselage shapes created can be exported and saved as CPACS files for further use in other software.

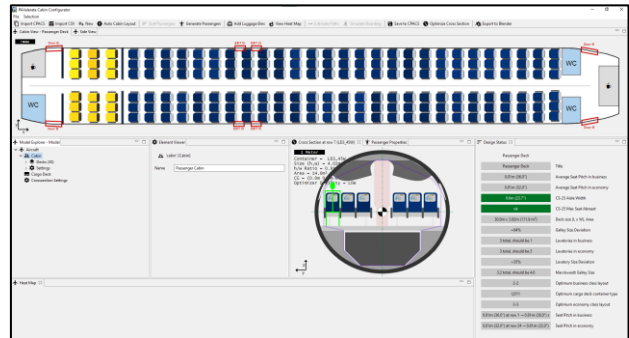


Figure 1: Screenshot of the CAFE user interface used for creating and editing cabin layouts.

### 2.2. CPACS

CPACS, which is the short form of “Common Parametric Aircraft Configuration Schema” is a file format and data structure type created by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) [4]. It is based on the XML schema and enables an easy and fast interdisciplinary data exchange, thus providing easy import and export capabilities to a variety of different tools [2]. The format is seeing continuous open source development with an increasing detail and depth and is steadily evolving as a standard across the German and European aircraft research community. Figure 2 shows an excerpt of an exemplary part of the XML file structure, here for a cabin deck element.

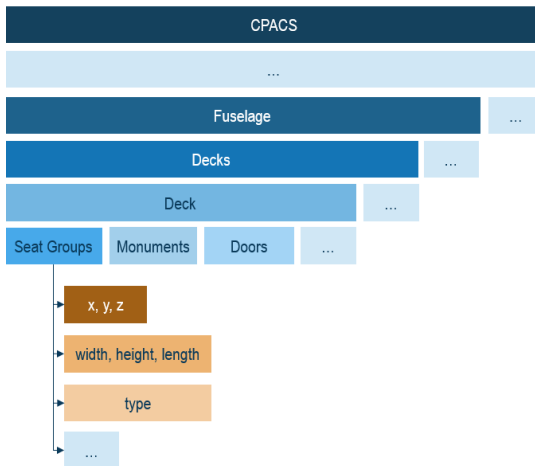
```

1 <deck uID="main_passenger_deck">
2   <name>Main Passenger Deck</name>
3   <x0>3.4</x0>
4   <z0>-1.5</z0>
5   <seatElements>
6     <seatElement uID="seat_group_1">
7       <name>Seats_1AB</name>
8       <nSeats>2</nSeats>
9       <type>economy</type>
10      <x>2.6</x>
11      <y>-2.5</y>
12    </seatElement>
13  </seatElements>
14 </deck>

```

Figure 2: Exemplary excerpt of a CPACS file showing the structure within the cabin deck element. This contains the deck positioning and a seat element containing various properties such as class type and location.

CPACS contains a complete object oriented description of the aircraft. Concerning the cabin, it provides information on all seat groups, galleys, lavatories, doors and more. Currently over sixty different value types exist within the cabin description. This includes for example the 3D object position and size, the seat type, the door type classification and more. An overview of the structure of the file is depicted in the following Figure 3.



**Figure 3: Overview of the CPACS data structure from the top-level element down to the various elements of the cabin.**

Within the cabin, all elements are defined as rectangular blocks without any deeper level of detail. A typical cabin file contains more than 300 different objects.

### 2.3. Blender

Blender is an open source 3D creation suite, which supports the complete 3D pipeline of modeling, animation, simulation and rendering. It is used for high quality image renderings and animated movie creation around the world [2].

The key feature for the purposes of this publication is the integrated Python API. It enables a programmatic access to all software functions and features of Blender without launching the user interface and thus enables the high degree of automation desired for the work of this paper.

## 3. MODELLING

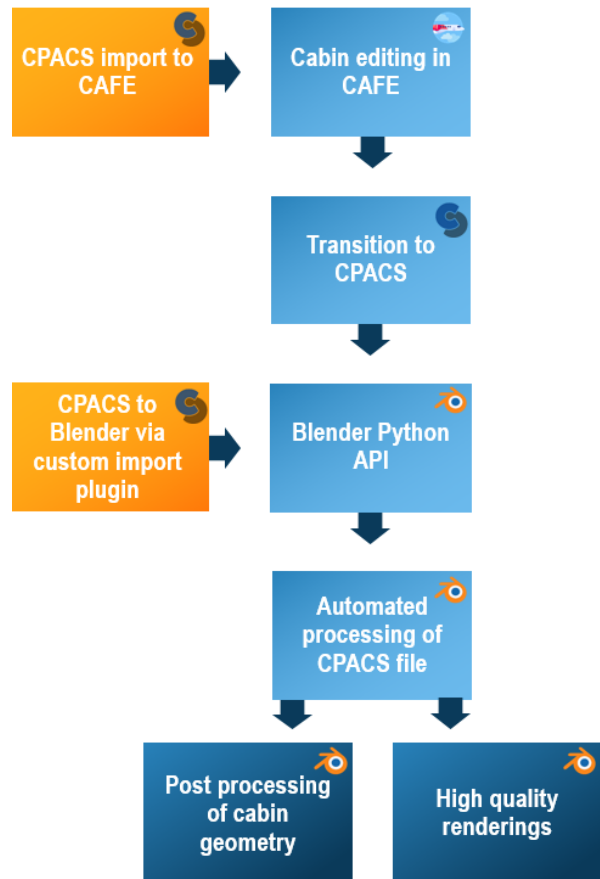
This chapter will highlight the user workflow for importing CPACS files into Blender as well as a detailed description of the script for the automated 3D cabin geometry creation.

### 3.1. Model Structure

The following Figure 4 highlights the key elements of model structure and the workflow. Starting with the

top left, CPACS can be input to CAFE where the cabin and fuselage can be edited automatically or manually. Afterwards, the model can be translated back to CPACS and is then feed into the Blender Python API, which then automatically processes the file. Alternatively, the CPACS file can be imported into Blender directly via a custom Blender plugin created by BHL.

After the automated processing, the detailed 3D geometry can either be used for high quality renderings or a further post processing of the geometry for various cabin assessments.



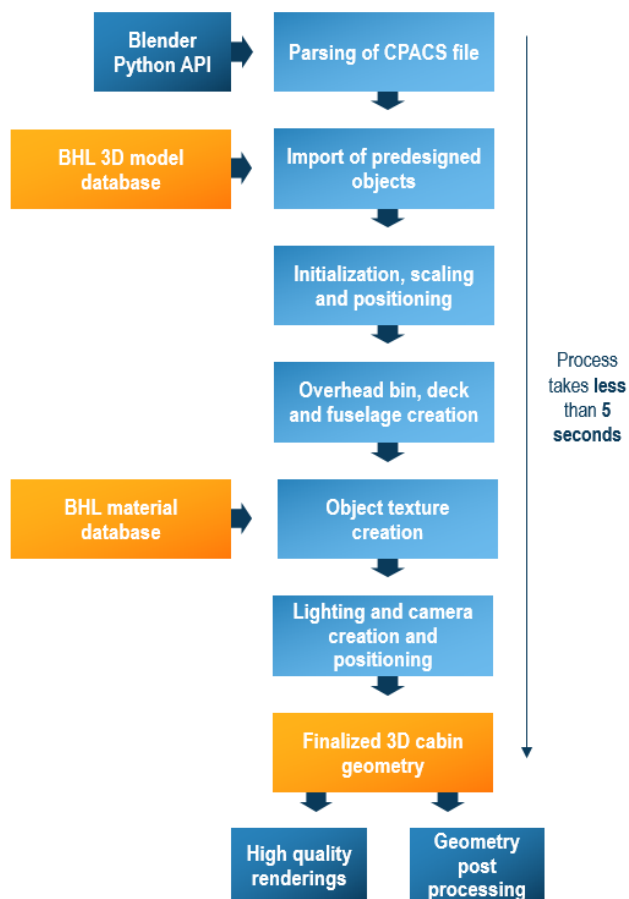
**Figure 4: Overview of the workflow from CPACS file to final rendering or 3D cabin geometry. The logos represent the execution type.**

### 3.2. Automated Script

The automated processing of the CPACS file from Figure 4 is described in more detail in the following Figure 5. Starting with the feeding of a CPACS file into the Blender Python API, the received file is first parsed and each CPACS sub element is piece by piece read out. After the detection of the cabin objects, the corresponding predesigned 3D models are imported from the BHL model database (see Figure 6 and chapter 3.3.). After the necessary objects are imported, the tool then initializes sizes and positions of the various objects of the cabin

according to the location and size information stored in the CPACS file.

In a next step, the overhead bins, the deck floor as well as the fuselage shape are created and positioned. As the overhead bins and the deck floor are not described in detail in the current CPACS schema version, the position of the overhead bins is derived from the location of the aisles and the cabin floor size is derived by a handbook formula.



**Figure 5: Detailed description of the Python script for processing the CPACS file within Blender.**

Next, all existing objects and models within the cabin environment are equipped with high quality material and texture information, which is based on a custom material and texture database created by BHL. In a last step, the lighting and camera objects are initialized and automatically positioned, providing an easy starting point for rendering the scene. Additional to the lighting added in this step, the imported objects themselves contain lighting within their geometry. The result is a high quality 3D cabin geometry containing all relevant parts of a cabin layout.

This script takes less than 5 seconds on a state-of-the-art business laptop to execute from the initial feeding of the CPACS file up to the final geometry, providing a rapid and easy possibility to generate detailed shapes out of a 2D cabin description in

CPACS. This geometry can then be used for high quality renderings and the geometry post processing.

### 3.3. Model Database

As mentioned in Figure 5 above, the cabin objects are imported as high quality pre-designed objects from the BHL model database. An excerpt of this collection of objects can be seen in the following Figure 6. It is solely designed and created for this purpose and features a variety of different objects for a cabin visualization. This contains not only conventional objects such as seats, galleys and lavatories in many different variations but also more unconventional elements such as tables, bars and staircases.



**Figure 6: An excerpt of the collection of the existing predefined cabin objects in the custom BHL model database.**

Lastly, multiple different linings for windows, emergency exits and doors as well as ceiling elements complement the collection.

### 3.4. Application Options

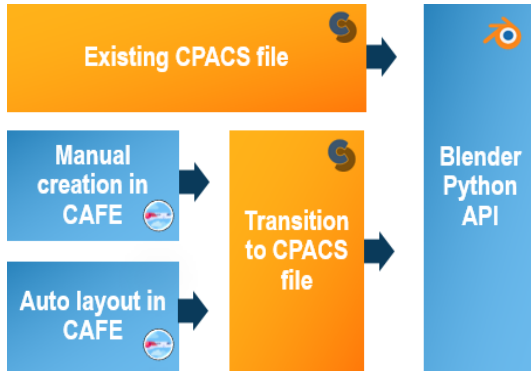
The application options for this automated Blender interface are versatile. Concerning the range of supported cabin and fuselage layouts, unconventional concepts such as blended wing bodies or multi deck configurations are supported as well. The only condition is the capability to model and describe the shapes of the objects within the CPACS file format.

Concerning the execution options, multiple different paths lead to the final 3D geometry. As it can be seen in Figure 7, three different variants exist. First, we created a custom plugin for Blender which enables a simple import like any other file type via *File* → *Import...* → *CPACS*. Second, a manual import of a CPACS file and a manual creation or editing of a cabin layout can be performed within CAFE. Afterwards, the cabin layout information is transitioned back into the CPACS format and is then automatically pushed to Blender via the Python API.

The final option is the application of an automated cabin design script, which generates final cabin layouts from scratch with minimal input. When



completed, the design is once again translated into CPACS and is then pushed to Blender.



**Figure 7:** The three different options for importing a CPACS cabin into Blender via the automated Python script. The logos represent the execution type.

## 4. APPLICATION

This chapter will give an overview of the two different application options of the script. This includes both the high quality rendering capabilities as well as the advanced 3D geometry assessment.

### 4.1. Renderings

The high quality rendering capability is the core feature of the model introduced in this paper and delivers a variety of realistic rendering results, which are highlighted in the following Figure 8, Figure 9, Figure 10 and Figure 11.



**Figure 8:** Rendering of a part of the AVACON research baseline cabin provided in the CPACS file format.

Figure 8 shows the rendering of a part of the cabin of the AVACON research baseline aircraft [5] economy class layout as seen from the front. This provides a first impression of the two-seat configuration at the windows for the selected seven abreast AVACON concept.

Figure 9 and Figure 10 show this 2-3-2 economy class layout from different angles and enable a remarkable sight into the aircraft's cabin.

This is all achieved by only using information stored in the CPACS file and turning it into a rich 3D cabin geometry within 5 seconds using a collection of cabin objects from the BHL model database. The rendering time itself strongly depends on the CPU and GPU performance of the used computer and takes around thirty minutes on a current state-of-the-art business laptop.

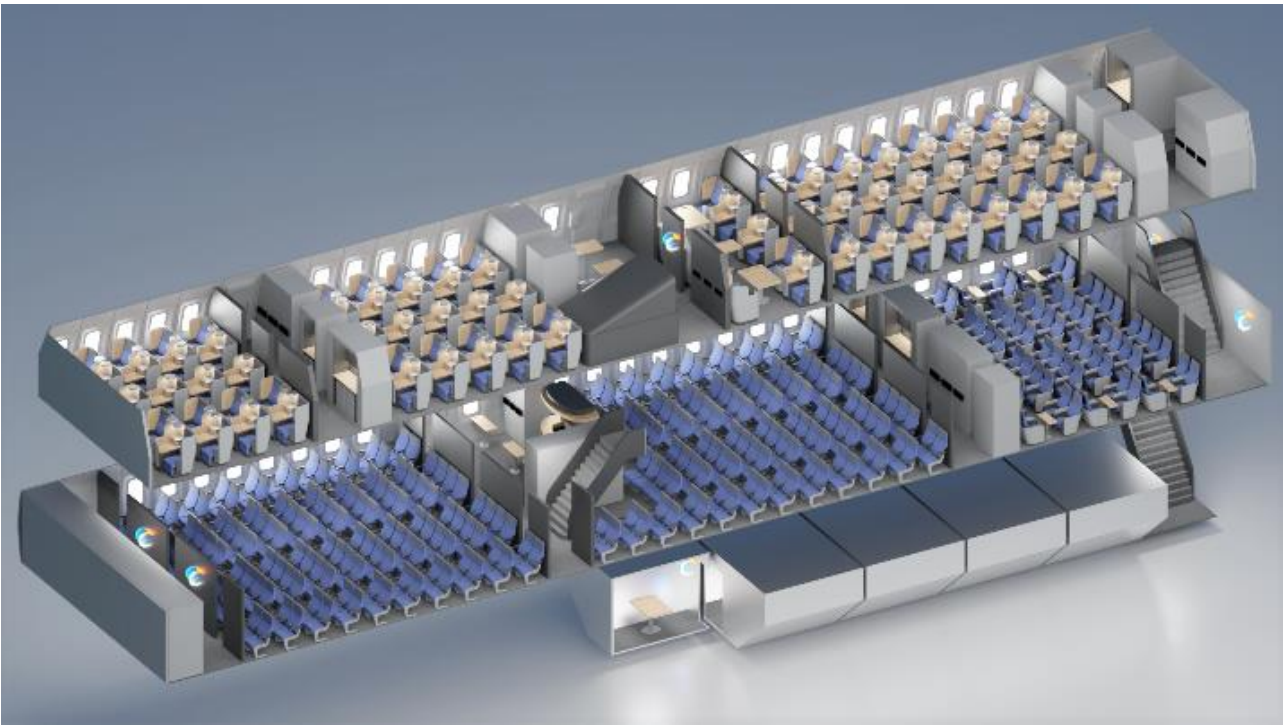


**Figure 9:** High quality rendering of a group of seats from a low angle.



**Figure 10: Rendering of a row of seats of the AVACON research baseline aircraft at daylight seen from a side angle.**

The following Figure 11 depicts the cabin layout of the three-deck Hy-ShAir concept created by BHL in 2019 as a contribution to the future of long range and low emission travel [6] [7]. The concept possesses two spherical hydrogen tanks located in front of and aft of the cabin, thus giving it the unique wide but relatively short cabin shape. Figure 11 highlights the second



**Figure 11: Rendering of the three-deck cabin layout for the Hy-ShAir concept by Bauhaus Luftfahrt for a future long-range travel scenario [6] [7].**

#### 4.2. Geometry Assessment

Concerning the assessment of the detailed 3D cabin geometry, there are multiple different application scenarios. First, there is the possibility to automatically detect object collisions between all the different elements within the cabin environment. This can be done very easily with the Blender Python API, which supports the detection of overlap between

aspect of the visualization capabilities of the Blender script.

Additional to the realistic interior renderings of cabin environments, it is easily possible to render high quality and easily comprehensible representations of cabin layouts with both conventional and novel design concepts from the outside. This results in the rendering of this three-deck configuration from an orthographic viewing angle and provides an overview of the various cabin aspects as well as the overall look and feel.

The cabin concept is completely describable within the CPACS format. The only exception to this are the cargo containers as well as some unconventional cabin elements, which are not yet supported by the CPACS schema. However, additional and more detailed cabin geometry information will be introduced in a future release of the CPACS schema by the DLR, thus simplifying the custom aspects of this Blender script even further and at the same time increasing the modelling capabilities and the depth of cabin concepts.

objects. This enables an early indication of issues concerning the placement of elements within the cabin and is superior to the CPACS file information as it considers the 3D shapes of objects. Exemplarily, a collision between a seat and a curved lining at the head level remains undetected in 2D but is visible in the 3D space.

Another possible use case of the geometry is a cabin air volume estimation, which is important for sizing

the environmental control system of the cabin. Additionally, this is for example relevant for the temperature change inertia of the cabin components that has to be considered for a detailed modelling of the temperature change during the cool down of a hot cabin before boarding.

Lastly, the verification of CS25 passenger safety regulations can be performed. These regulations assure that enough space is available for passengers and doors, for example during an emergency. The tool can thus detect if the necessary required space on the aisles, in the safety areas and in front of the doors is provided in 3D.

## 5. CONCLUSION

Concluding the results of this publication, the goals set have successfully been achieved and the demand described in the first chapter has successfully been satisfied. The automated geometry generation uses multiple different import options to automatically create a rich 3D cabin geometry within less than five seconds. The geometry is ready for a transition into VR without many additional modifications.

High quality cabin impressions can be rendered within Blender with minimal additional effort such as repositioning the camera or adapting the lighting of the scene. The resulting 3D cabin geometry can be assessed concerning an air volume estimation, 3D collision detection between objects as well as CS25 passenger safety regulations.

Overall, the model delivers the capability to get a fast 3D impression of a cabin during the early design phases using a high degree of automation and the industry standard CPACS. Furthermore, the detailed 3D cabin geometry enables an enhanced 3D assessment not possible before. Novel cabin concepts can thus be experienced from a completely different angle, benefiting both passengers and manufacturers of future aircraft.

## 6. OUTLOOK

This introduced model only marks the first step into a enriched cabin design experience with multiple additional application options.

In a next step, the cabin model will be transitioned into a virtual reality environment using a game engine such as the Unity Engine™ [8] or the Unreal Engine™ [9]. This provides a fast and easy possibility to experience the cabin design from a completely new perspective and can enable both manufacturers and potential passengers to get a new subjective feel of the cabin or layout changes during the early concept phases. Furthermore, the subjective experience of passengers using the model in VR can be analyzed and modifications to the cabin layout and their influence on passengers can be assessed.

The use of augmented reality on the other side can provide detailed impressions of specific cabin elements, such as a novel seat concept, projected life-size into the current environment. This is possible on regular smartphones using tools such as Apple® ARKit [10] and does not require additional hardware or software.

Concerning the 3D geometry, a further assessment of layout changes regarding the impact of passengers and their behavior within the cabin can be performed using an advanced boarding simulation and a more detailed passenger model. The benefit here lies in the fact that the detailed 3D geometry may enable a higher degree of modelling freedom for critical paths of the boarding simulation such as the luggage stowing process as well as other applications such as emergency evacuation scenarios.

Lastly, the geometry can be transitioned to third party software enabling a cabin airflow assessment using CFD. This could benefit the assessment of the cabin airflow and the potential distribution of COVID-19 in dense cabin environments and may enable the identification of critical cabin elements.

## 7. ACKNOWLEDGEMENTS

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