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A collaborative knowledge-based method for the interactive development of cabin systems in virtual reality

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ABSTRACT

Progressive digitization in the development phase of systems is leading to shorter development times and lower costs. At the same time, the interactions in more complex systems are increasing and become more nested, which affects the understanding of system dependencies for humans as well as modeling these. This results in the challenge of digitizing the knowledge (rules, regulations, requirements, etc.) required to describe the system and its interrelationships. An example of such a system is the aircraft. In practice, usually, the technical design of the cabin and its systems is done separately from the preliminary aircraft design and the cabin results will be integrated late in the aircraft development process. In this paper, a proposal is given for a conceptual design method that enables a cabin systems layout based on preliminary aircraft design data (parameter set). Therefore, a central data model is developed that links cabin components to several disciplines to enable an automated layout. Here, knowledge is stored in an ontology. Linking the ontology with design rules and importing external parameters, missing information needed for preliminary design of cabin systems can be generated. The design rules are based on requirements, safety regulations as well as expert knowledge for design interpretation that has been collected and formalized. Using the ontology, an XML data structure can be instantiated which contains all information about properties, system relationships and requirements. So, the metadata and results of heterogenous domain-specific models and software tools are accessible for all experts of the layout process in a holistic manner and ensure data consistency. Using this XML data structure, a 3D virtual cabin mockup is created in which users have the possibility to interact with cabin modules and system components via controllers. This virtual development platform enables an interaction with complex product data sets like the XML file by visualizing metadata and analysis results along with the cabin geometry, making it even better comprehensible and processable for humans. So, various new cabin system designs can be iterated, evaluated, and optimized at low cost before the concepts are validated in a real prototype. For this, the virtual environment provides a platform that integrates all related disciplines, experts, research partners or the entire supply chain to improve communication among all stakeholders by directly participating and intervening in the evaluation and optimization process. Moreover, the use of VR is being investigated as a new technology in pre-design phase to exploit the potential of knowledge acquisition in immersive environments early in the development stage.

1. Introduction

The constantly advancing development of technologies, such as liquid hydrogen, and the expansion of functions as well as their integration leads to more complexity in products and systems (ElMaraghy et al., 2012). In addition, the complexity increases when individual systems are grouped into a System of Systems (SoS). In this case, the individual system components have operational independence, while the overall purpose is to provide a function that cannot be provided independently by the individual systems (Tekinerdogan and Erata, 2020). This includes, for example, airplanes and automobiles. The challenges posed by such complex systems are traceability of requirements, interdependencies, and a significant increase in the amount of information that engineers have to deal with. Causes are for example the heterogeneous models and different levels of detail of the data. Changes within a domain and their influence on other systems are not directly apparent (Stark et al., 2010). Instead, these are identified late in the design process, leading

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to incremental adjustments and expensive work. At the same time shorter development times of these products are socially and economically demanded while maintaining the same quality, in order to incorporate new technologies or to meet market requirements. Especially for customizing, reconfigurability through modularity and flexibility are important. In many cases this leads to the necessity of adding or removing elements and capabilities of complex systems. As recently seen with the Covid-19 pandemic, companies together with research facilities in the aircraft industry are trying to generate new concepts according to the new situation and rapidly adapt their products and services where necessary (Moerland-Masic et al., 2021) This requires a fast development cycle without violating the applicable requirements or guidelines. One driver for managing these challenges is digitalization, which promotes global value chains, complex networks, co-design, and collaborations between cross-functional departments through an end-to-end digital thread.

The comprehensive digitization of the product life cycle processes promises the creation of a complex system that can respond to new requirements and circumstances in a partially automated and flexible manner. Each process automatically sends information about itself and communicates with one another, increasing predictive capacity, product monitoring, and traceability. The most important aspects of networked and digital systems are improving communication and connectivity, increasing visibility, creating transparency in data knowledge processing, and increasing predictive capacity through simulations and optimization functions (Jaskó et al., 2020). For this purpose, the concept of digital twin is applied (Jaskó et al., 2020; Singh and Willcox, 2018). This approach is based on creating high-resolution digital models to mirror the lifecycle of a product and to test it in a virtual environment (Jaskó et al., 2020; Singh and Willcox, 2018). In doing so, it collects and uses information from previous phases for product testing in order to make decisions by experts in a shorter time. The data for this is provided by the Digital Thread. The Digital Thread is a data-driven architecture that links information from the product lifecycle and connects the entire supply chain. In addition, it contains all the information needed to create and update the digital twin (Singh and Willcox, 2018). A basic requirement for this is the development and implementation of linked data models that do not communicate via document-based information exchange (Singh and Willcox, 2018). In companies, these are mostly product-lifecycle-management databases, but the trend is towards the use of models. Examples of such data models include computer-aided design tools and modeling languages such as SysML, UML, and XML (Singh and Willcox, 2018). In this approach, system information is based on models and not exclusively on textual information, thus placing a cross-disciplinary system model at the center of development (Muggeo and Wolters, 2019). The potential lies in reusability, better documentation, and clearer product structure through linked models (Negele et al., 1999). Complex relationships can be made analyzable and navigable, enabling a better understanding of the system (Negele et al., 1999). Information dissemination is important and key to enable teams to act independently in their domain (multidisciplinary) as well as in a larger network (interdisciplinary) (Jones et al., 2020).

In this paper a research approach and method for the conceptual design of aircraft cabin systems is presented. Thus, a virtual development platform is built with an interactive 3D model of the cabin including systems. The aim of the platform is to integrate and compare new technologies more quickly and to better understand the interrelationships within the cabin and its system architecture. This will contribute to a virtual end-to-end overall system capability. One technology that is gaining more and more influence in the design process over the last years is virtual reality (VR) (Coburn et al., 2017). In industry, this technology is used, for example, for virtual training or the presentation of prototypes to the customer. Successful examples of the use of immersive technology in combination with a digital mockup include Airbus (visualization of equipment in the production environment for assembly workers) (Cohen and Duboé, 2018), Lockheed Martin Tactical Aircraft Systems (evaluation and visualization of maintainability of a design) (Abshire et al., 1998), and research at Beihang University (immersive maintainability verification and evaluation system) (Guo et al., 2018).

One focus is on the area of virtual testing of new cabin system designs. Due to the complexity of the overall cabin system, dependencies as well as requirements that have led to the placement of a cabin component are not directly recognizable. A digital cabin enables the tracing of requirements and the testing of layouts for plausibility. With the help of controllers, the user interacts with the virtual environment and has the opportunity to experience the aircraft cabin and its systems realistically. The direct emotional feedback of the user in the early model stage as well as the faster implementation of design changes allow considerable flexibility, time savings, and cost reduction compared to a real mock-up. Some examples of the use of virtual reality are both the evaluation of regional aircraft cabin interiors (De Crescenzio et al., 2021) and business jet aircraft cabin interiors (De Crescenzio et al., 2019) by Crescenzio et.al.

This research report presents a methodology for developing cabin systems that meets the purpose for traceability, digitization, and automatic reconfiguration. Therefore, an integrated and collaborative approach is presented to collect and formalize requirements and rules and store them in a data model. This means that a high-resolution model of the cabin can already be generated on the basis of pure preliminary aircraft design data and used for advanced evaluation methods and simulations. The subsequent connection to virtual reality improves the understanding of dependencies and interrelationships by querying and visualizing this metadata.

The remainder of this paper is organized as follows. Section 2 describes the component classification as well as safety regulations for the conceptual configuration of aircraft cabins. Section 3 explains the used methods, ontologies, and integration to virtual reality. The results of two use cases are explained in Section 4. Moreover, the assumptions are described followed by a discussion. Finally, Section 5 concludes the paper.

2. Information and knowledge for cabin system design process

Different system groups are required for the operation of the aircraft cabin. These are, for example, the electrical system, water/waste system and the digital system. When designing the cabin and its systems, many requirements, such as safety regulations, as well as system couplings must be considered. Moreover, interactions occur that are not always directly recognizable due to the overall system complexity. In addition, the available space for the placement of cabin systems is limited by the structure of the fuselage. Therefore, all this information needs to be considered in the cabin system design algorithm and is done by linking the different disciplines. The following two subsections present the classification of cabin systems and the safety requirements that were used in the development of a conceptual design method.

2.1. ATA classification of cabin systems

Various systems are required for the essential and economical operation of an aircraft cabin. These, in turn, can be divided into many subgroups with overlapping affiliations. In addition, the interactions and dependencies among them and with respect to the passenger are critical to the layout process. For example, some systems require barrier-free use by the passenger or must be directly accessible in an emergency. For a precise differentiation of the systems, a classification is made according to the Air Transport Association (ATA) chapter definition. This enables consistent

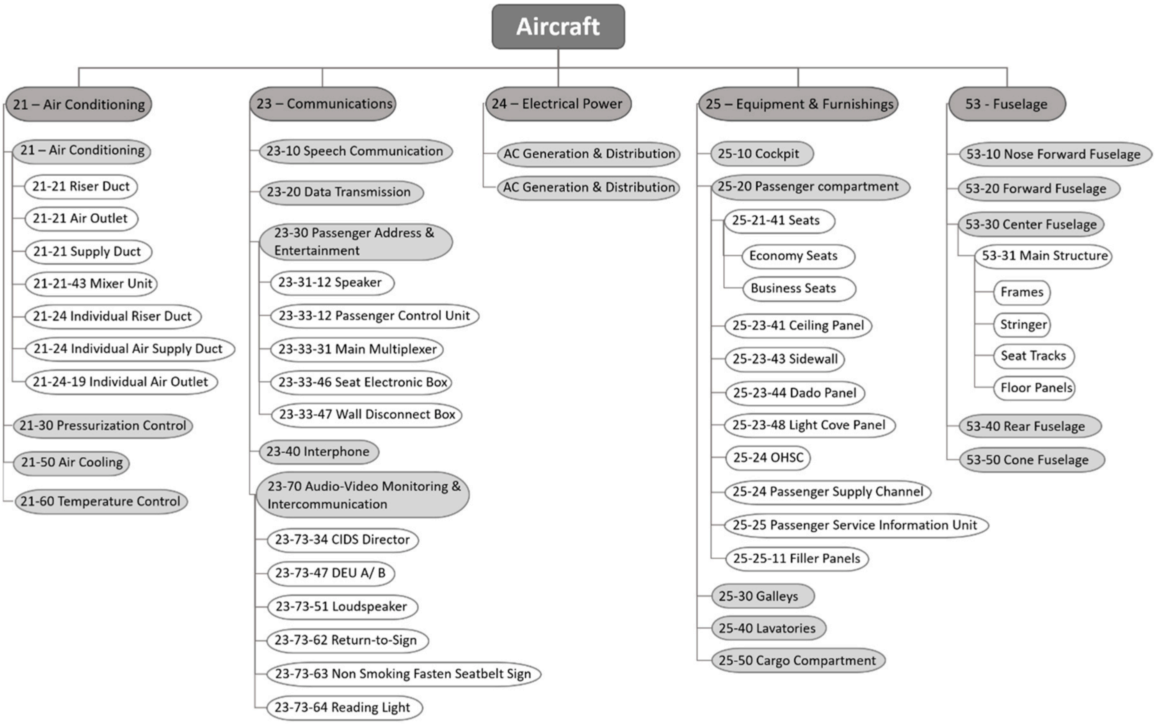


Fig. 1. Subdivision of the Air Transport Association chapters with applicable cabin components.

working and readily identification of the relevant components and systems. In total, six main groups can be identified for the cabin systems. These are the systems for air conditioning (AC), communications, electrical supply, lighting, oxygen supply and water/waste. Fig. 1 shows the classification according to ATA chapters as well as some subsystems (Air Transport Association, 2021).

Using this classification, the relationships of the components to each other are determined and the requirements for the placement of the respective components are derived from the component-specific properties. These are then stored as functions for the cabin conceptual design algorithm.

2.2. Safety requirements for cabin systems

An important aspect in the methodical configuration of cabin systems are the safety requirements. These are summarized as the European standards in the Certification Specifications for Large Aeroplanes CS-25 issued by EASA (EASA, 2007). The minimum requirements specified here must be met for certification of an aircraft in this class. Therefore, the safety requirements are considered in the conceptual design of the systems and subsequently examined for compliance using a developed test method. Examples include compliance with clearances in front of emergency exits (CS §25.810 (c)1) or accessibility of oxygen masks for each seated passenger (CS §25.1447 (c)1) (EASA, 2007). A developed requirement testing protocol of this paper will visually communicate safety compliance. Requirements such as fire resistance or compliance with bending radii are not considered in this work for now.

A higher level of detail is required to evaluate new cabin system concepts considering, for example, safety requirements. In order not to oversee potential influences of new configurations, these have to be compared to a reference model of the same level of accuracy (Wöhler et al., 2019). Yet the cabin system process is decoupled from the preliminary aircraft design. In the latter, a baseline aircraft configuration is generated starting from a limited set of top-level requirements like range, cruise, and payload size (Ciampa et al., 2013). Accordingly, the level of detail is too low for the evaluation of cabin systems. A first approach was shown by Engelmann et al. (2020), who use this parameter set to derive cabin models for the study of boarding simulations. However, the cabin is modeled at a lower level of detail and its systems are not even considered. Therefore, the presented method of this paper uses additional formalized knowledge to configure the cabin systems so that a high-resolution model can be generated automatically based on the parameter set of the preliminary aircraft design. As a result, disruptive concepts can be investigated and more advanced research methods such as production planning or comfort evaluations can be performed.

3. Methodology

In the following section, the new developed methodology of this research for the conceptual design of the cabin systems and the subsequent transfer to virtual reality is presented. The presented data sources from Section 2 were used for a digital knowledge data model for the automated configuration of the cabin and its systems.

3.1. Conceptual design process and integration to virtual reality

The process from the configuration of the cabin systems to the display and interaction with the 3D models in virtual reality is shown in Fig. 2. First, a design algorithm in Matlab (MathWorks, 2021) is used to generate the cabin layout including the systems. Simple geometric shapes are used to represent the cabin components. The rules for placing each system component are derived from the interactions and safety requirements mentioned in Chapter 2. Here, the layout of the cabin varies with the selected requirements. Either an already existing external aircraft geometry is used, following an outside-in approach. Or the cabin layout is determined by self-selected parameters and requirements and allows an independent cabin layout from preliminary aircraft design requirements. An external connection can be made e.g. from the Common Parametric Aircraft Configuration Schema (CPACS) (CPACS, 2020). This contains a parametric description of aircraft configurations and

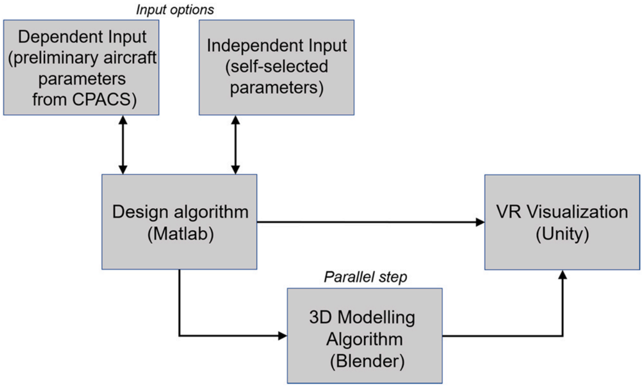


Fig. 2. Schematic process flow for cabin conceptual design and visualization in virtual reality.

enables the exchange of information for the air transport system. The placement and design of the systems were each based on these inputs.

To ensure that the data can be displayed in a virtual environment without losing information, an object-oriented structure is used (Mainzer, 2013). This offers the advantage of being able to define new classes at any point or to make increments with less effort. The created cabin components are stored as individual objects and managed via a virtual container. Here, information of a component, like e.g. the ATA affiliation or construction dimensions, is stored as attributes in the object. Further information such as connections between the components is likewise deposited in the object structure. In the next step, these information packages are exported and transferred to the virtual environment. In parallel, the information about the construction dimensions and positions is transferred to the graphics software Blender (Blender Foundation, 2021) for the realistic modeling of the components. In Blender, the simple geometric shapes are replaced by three-dimensional and high-resolution objects. The generated cabin model is then imported into the Unity 3D environment (Unity Technologies, 2021).

3.2. Design algorithm for the cabin system layout

For the automated and variable design of cabin systems, many requirements and information have to be processed, which in turn can influence each other. Therefore, a design algorithm is created in Matlab to link this knowledge and use it for the system layout.

3.2.1. Framework of the cabin system algorithm

The algorithm is based on an object-oriented structure. The modules of the program are referred to as objects, which are each instantiated on the basis of a class definition. The class definition contains, among other things, definitions for attributes and methods. The attributes of an object contain the data structure of the object, while the methods describe the behavior of an object in the program context. Here, a class is created for each cabin component type (e.g. seat). This is used to instantiate objects for the required cabin components, in which component-related information is stored as attributes (properties). This includes exemplary the name, the construction dimensions, the position or the ATA affiliation of the generated cabin object. In addition to the cabin component class, there is another class for links (relationships) and one for requirements (safety requirements and human factors). Specific attributes are also stored in these.

3.2.2. Procedure of the design algorithm for the cabin system layout

Fig. 3 shows the schematic workflow and process steps of the design algorithm. The starting point is the import of structural aircraft data, like the fuselage. All relevant data for the cabin system configuration is filtered out of the CPACS file and transferred to the geometrical system layout algorithm. This data can be used to define the boundary box for the cabin area in which the cabin systems should be placed. In addition, the user can specify parameters and variables for the geometries of the cabin components.

When the algorithm is run, a configuration variant for the aircraft cabin and its systems is generated based on the imported data, parameters, and requirements. During the process, the cabin components are geometrically placed in the defined cabin area. Thereby, an object of a defined class is instantiated for each cabin component. The instantiation of an object is done by implemented rules which are stored as specific functions for the placement of each

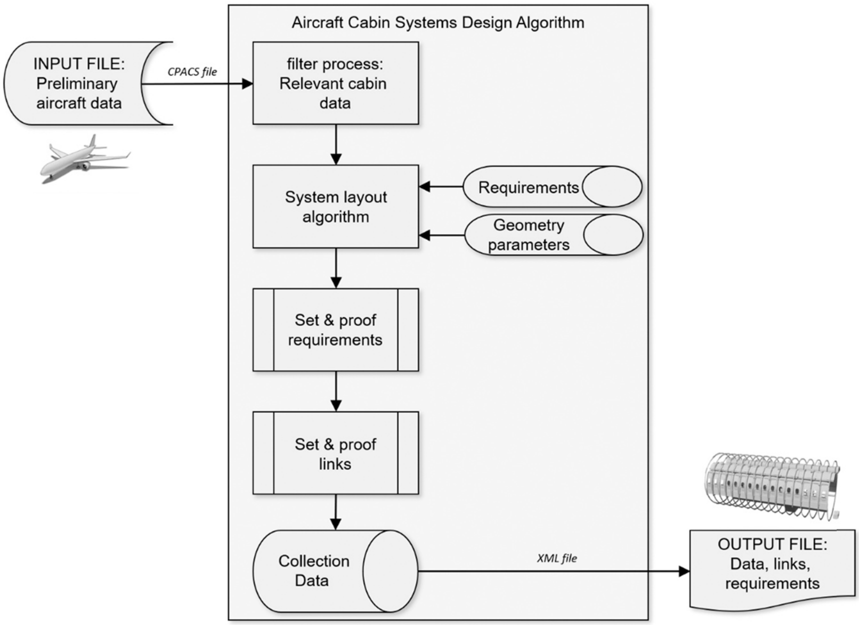


Fig. 3. Work flow for cabin system design algorithm.

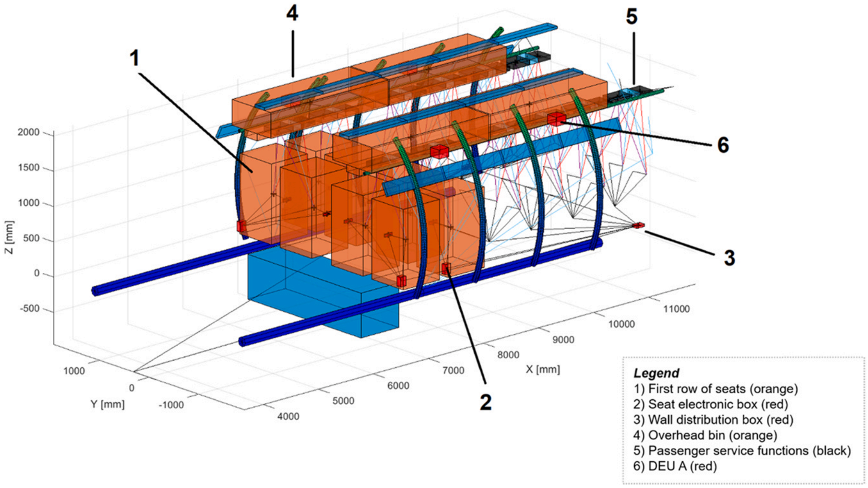


Fig. 4. Visualization of cabin systems with simple geometric shapes in Matlab for case 1.

component. Based on geometric conditions or dependencies, a position in the cabin is sought. If the position meets all criteria, the position data is transferred and an object with the corresponding information is generated. The values for the attributes are taken from a general, predefined parameter list stored in Matlab. Before starting the conceptual process, the user can easily modify it and thus adjust the dimensions of individual components. This enables a fast exchange for testing new components.

During the process, all generated objects are managed via a virtual data container. This stores the identification number (ID) of the objects, allowing unambiguous referencing. The unique ID allows specific objects to be accessed when they are needed for the placement of other components or for the creation of links. In addition to the central management of all cabin objects, link objects and requirement objects are also stored in a separate virtual container. A link object is created whenever two components have a relationship to each other. The type of link is also stored as an attribute. Examples are the mechanical coupling of two objects or an electrical signal transmission. Beyond that, links are also created between requirement objects and components. If a requirement is considered in the design of a cabin object, both are linked to each other. This way, the reason for the placement of individual components can be traced and the relationship expressed. In addition, this feature can be used to create a visual requirement test protocol. In case a safety aspect cannot be met, it will be visible within the virtual environment.

The generated virtual containers can be transferred to an XML format via an export function to further processed the data in other programs. The connection to Unity and the transfer of complex relationships using a generated XML file are described in the next section.

3.3. Modeling the virtual reality platform with Unity

Unity, a runtime and development environment for computer games, is used to model the cabin and its systems in virtual reality. This offers many possibilities for interaction with the cabin objects. For example, animations, materials, or physical properties can be assigned to the objects, increasing the intensity of immersion for an aircraft cabin scene (Unity Technologies, 2021). For the virtual cabin environment, a standard scene is built. Here, the lighting of the scene as well as a script for the import are stored. The latter enables the import of the XML file generated in Matlab and the 3D model file created in Blender. Interaction between the user and the virtual cabin is enabled by another script component. In this script component, the functional sequences for the use of the VR controllers are defined as well as sequences for the movement or the camera adjustment. If the user moves in the virtual environment and points at a cabin object with a controller, one can interact with it. Either the information of the object is displayed (name, construction dimensions, ATA chapter) or connections to the other objects are visualized. In doing so, the script accesses the stored XML file and searches the matching links via the object ID. As soon as a matching ID is found in a link object, further linked cabin objects are highlighted in color. When dependencies of a system component are displayed, all linked systems can thus be highlighted and made visible in color. Subsequently, an export function generates an executable application from the cabin scene. The HTC Vive Pro Eye series is used as the output medium. This supports the desired implementation of the requirements for immersion and fidelity of the built scene with its dual OLED displays and a resolution of 2880 × 1600 pixels (HTC VIVE, 2021). An example application is described in more detail in the following section.

4. Results and discussion

The entire process from the conceptional design of a system to the interaction with the cabin in VR is shown in the following section using two different layout cases for the overhead stowage compartment (OHSC) and the passenger service functions. These complex subsystems are suitable as a demonstration because it includes a representative selection of different components and connections of a complete aircraft cabin. For the cabin study of the two different layout cases, an Airbus A320 cabin geometry is used (Fuchs et al., 2020a, 2020b). The first case shows a cabin layout with a standard size overhead storage compartment and one passenger supply channel (PSC). In contrast, the second case examines a larger OHSC that uses two supply channels to distribute passenger service functions.

4.1. Cabin model generation with Matlab for both use cases

At first, the parameters and properties of the cabin components are defined in Matlab. Fig. 4 shows a section of the resulting system design with simple geometric shapes, exemplified by the first case study. The representation and execution itself are equivalent to the second case study. The first two rows of seats (1) and overhead storage compartments (4) are shown as orange blocks. Moreover, the seat electronic box (2) and the wall distribution box (3) are shown as red blocks. The passenger service functions (5) are above the seats in the passenger supply channel and the decoder/encoder unit (DEU A)

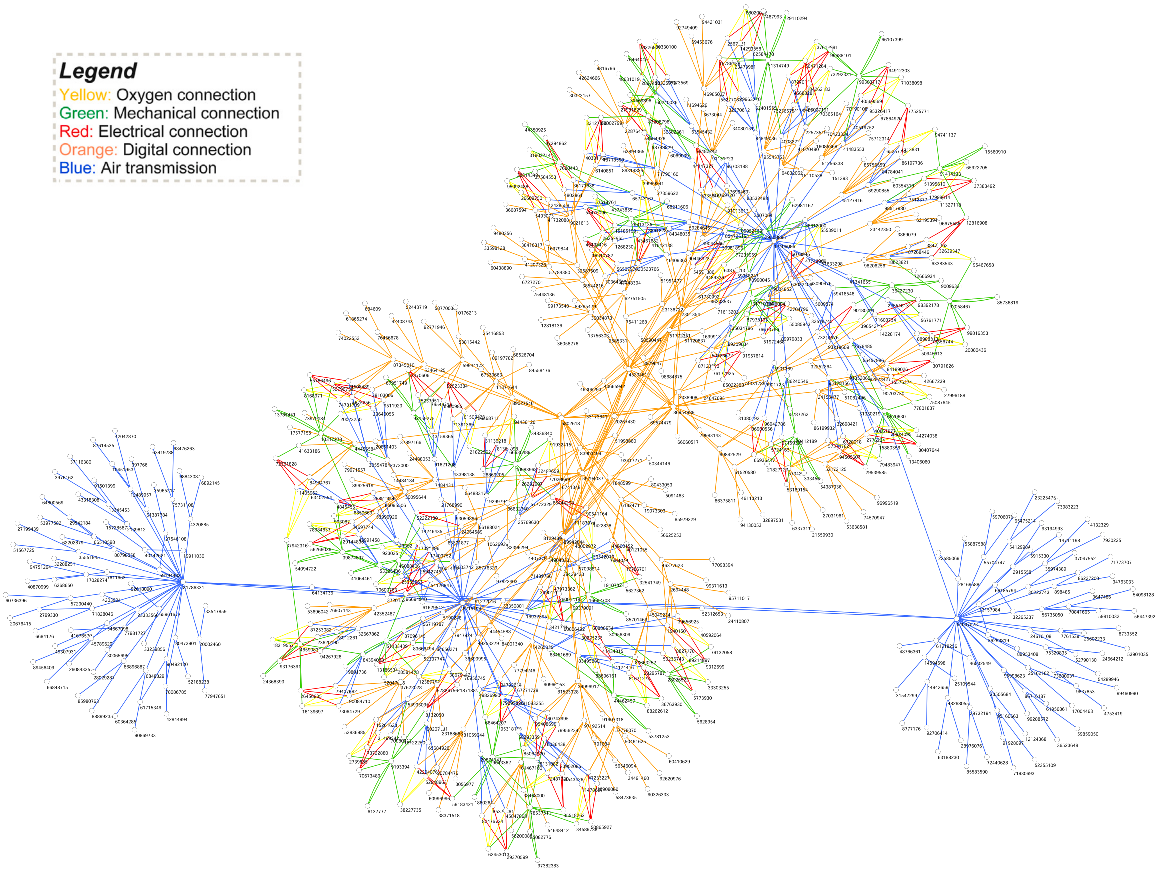


Fig. 5. Network diagram of all cabin components for study case 1 visualized with Cytoscape. The network consists of 936 nodes and 1798 links.

(6) is behind the OHSC. In addition, some components of the air conditioning system are shown. These are the mixer Unit, the supply ducts, the riser ducts and the air outlets. All air conditioning system components are colored blue. The individual lines show the links between connected cabin objects.

Fig. 5 shows the network diagram of all connections between the generated cabin objects for the exemplary cabin in case 1. The graph was created using the data of the XML file and the open source software platform Cytoscape (Cytoscape, 2020). Individual circles represent the cabin components and are identifiable by their ID. The lines between two circles represent connections between components while their color shows the connection type. Here, the color green shows a mechanical connection. Red describes an electrical connection and orange a digital connection. For the transmission of air, as in the air conditioning system, the color blue is used. Yellow, in turn, stands for an oxygen connection, such as between a seat and the oxygen masks. Based on the figure, the complexity of the overall cabin and its systems can be clearly seen due to the many interdependencies between them.

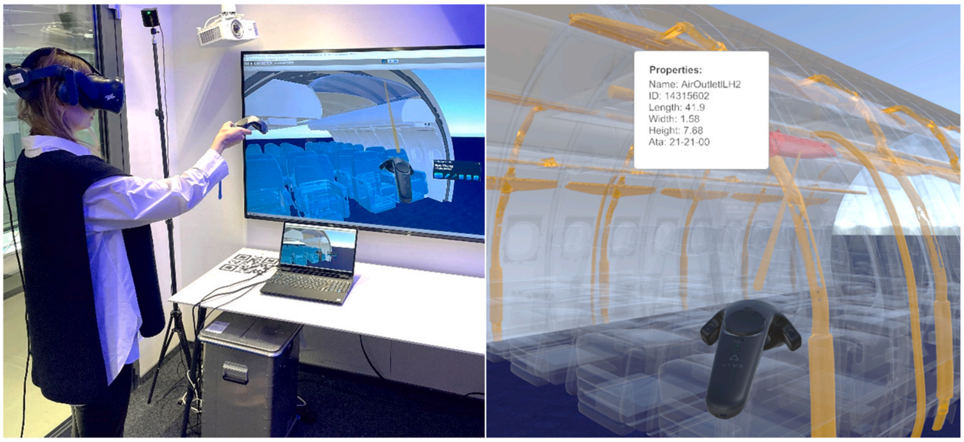
4.2. Virtual reality setup

Finally, the generated model is transferred to the virtual environment in Unity. Fig. 6 shows the user and its view during the cabin simulation in VR. The user has the possibility to interactively experience the cabin with the VR headset and controllers. As shown in Fig. 6a, the user can move freely in the VR setup in the laboratory. To interact with the virtual environment, to teleport, and to select individual cabin objects, a controller is used. Fig. 6b shows the live view of the HTC headset and how the user sees the virtual cabin. After the selection of an object the stored attributes are displayed in a pop-up window. As in this example, the properties of the air outlet are listed in the pop-up window (see Fig. 6b). Additionally, the user has several interaction modes. For instance, the associated system group of a selected cabin object can be displayed. Therefore, the generated links between the cabin components are used. In the shown example, the air conditioning system is highlighted in yellow while other components are displayed transparent.

4.3. Comparison and discussion of the two use cases

Fig. 7 shows the results of the method in the virtual environment for the two case studies. For a better overview, only one section of the entire cabin is shown. The figures of the first row show a front view of the cabin with a selected and highlighted seat (red) as well as an OHSC (orange). For this seat, the requirement for accessibility of oxygen masks is visualized. Here, a geometric block represents the potential area in which a mask box must be placed so that it is within reach. In both cases, a box is located in this area and is highlighted in yellow. In addition, the fulfilment of the requirement is confirmed by the color green.

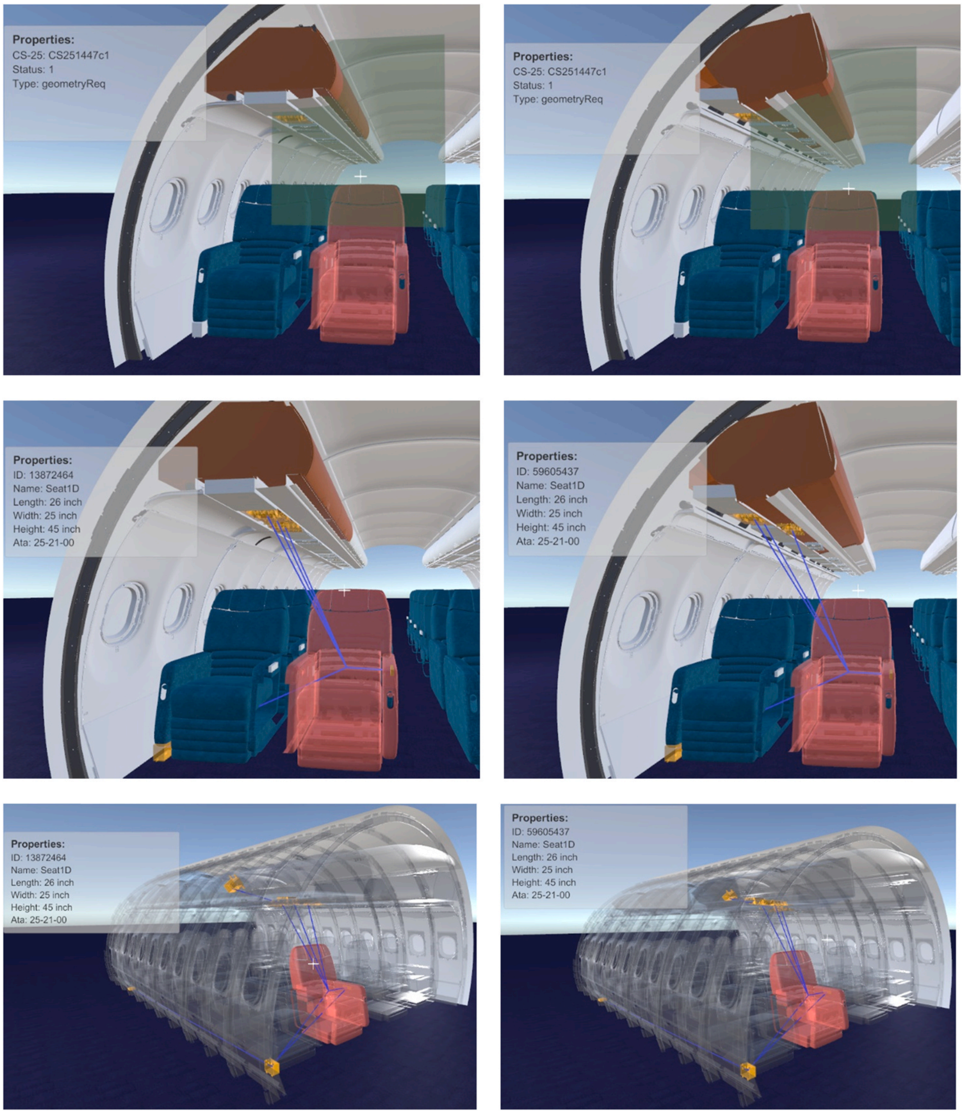
Another function within virtual reality is the representation of dependencies to other system components. With the help of the links, connections can be represented by lines and visualized in the 3D cabin. This gives the user a direct overview of all relevant information. The middle figures show the connections of the seat. These links to the passenger control unit and the seat electronic box as well as to the passenger functions. For case 1, the latter are in one PSC (Fig. 7a), while for case 2, the oxygen masks and the individual air outlets are in one channel and the passenger control unit is in another (Fig. 7b). The figures below show part of the digital and electrical system chain. This includes the DEU A and the wall distribution box. Comparing the images, it can be seen that the larger overhead storage compartment results in a different placement of



Properties:
Name: AirOutletlLH2
ID: 14315602
Length: 41.9
Width: 1.58
Height: 7.68
Ata: 21-21-00

a) User standing in VR setup interacting with cabin model **b)** Live view of HTC headset seen by the user

Fig. 6. The virtual cabin with the highlighted air conditioning system for case 1. The related properties of the air outlet are shown in the upper left canvas.



Properties:
CS-25: CS251447c1
Status: 1
Type: geometryReq

Properties:
CS-25: CS251447c1
Status: 1
Type: geometryReq

Properties:
ID: 13872464
Name: Seat1D
Length: 26 inch
Width: 25 inch
Height: 45 inch
Ata: 25-21-00

Properties:
ID: 59605437
Name: Seat1D
Length: 26 inch
Width: 25 inch
Height: 45 inch
Ata: 25-21-00

Properties:
ID: 13872464
Name: Seat1D
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Length: 26 inch
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Height: 45 inch
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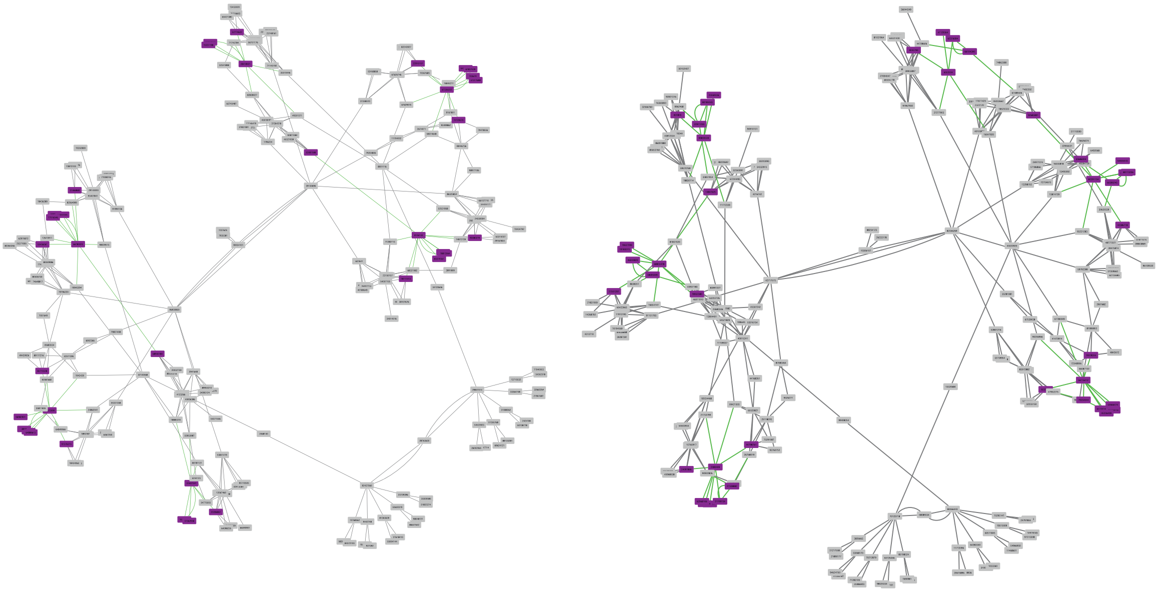
a) Case 1: Standard OHSC with one supply channel **b)** Case 2: Larger OHSC with two supply channels

Fig. 7. The results of the two layout cases in VR. The related properties of the system component are shown in the upper left canvas and the link to other cabin systems is shown by lines.



a) Study case 1: Standard OHSC with one supply channel, 216 nodes and 389 links.

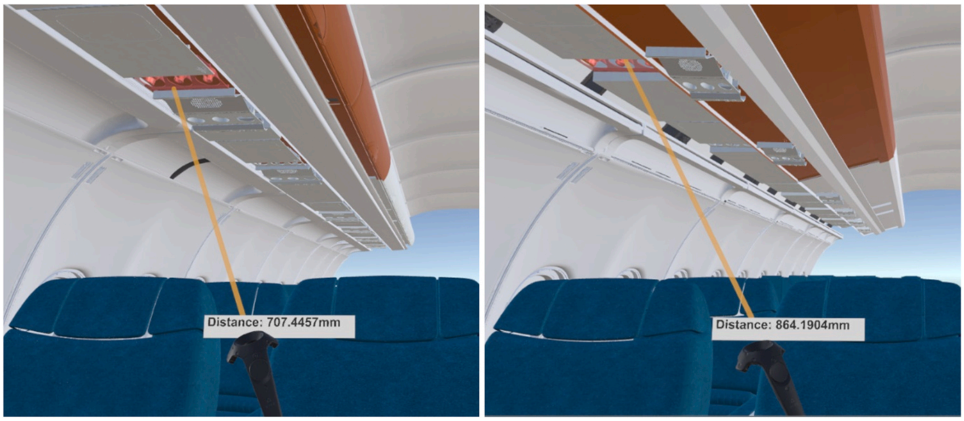
b) Study case 2: Larger OHSC with two supply channels, 222 nodes and 393 links.

Fig. 8. Network architecture of the cabin section for the two layout cases.

the DEU A in the cabin. This new formation of the system architecture can also be seen in the comparison of the networks (Fig. 8). Due to the different geometric and functional requirements, there are other links and dependencies between the system components. Thus, the first case in the shortened version consists of 216 nodes and 389 links (Fig. 8a), while the second case has 222 nodes and 393 links (Fig. 8b). In addition, it can be seen that there are new, different connections between the system components and that the two networks differ in structure. As an example of a system group, the mechanical connections (green) between the passenger service functions and the supply channel (both purple) are highlighted. The new links can be considered when evaluating and selecting the final configuration. The advantages and disadvantages can thereby be traced easier. The design of case 2, for example, allows the construction of a more compact and modular solution that saves installation costs and reduces cable weight.

Another aspect is the analysis of the cabin layout. Based on the prepared data, these can be used interactively in virtual reality for proband tests. Fig. 9 shows the possibility of measuring the distance between the seat and the passenger service functions for evaluating accessibility. The controller is located at shoulder level and measures the distance from there to the individual air outlets. The distance for case 1 is 707 mm (Fig. 9a) and for case 2 approximately 864 mm (Fig. 9b). This data can be used to select and evaluate the layout. In this example, the air outlets in case 1 are also accessible for the smallest passenger user group (5th percentile, female, Asia) from an anthropometrical point of view and offer more comfort.

The examples show that linking the cabin system design algorithm in Matlab with virtual reality enables the user to visually grasp the relationships in the cabin more quickly. The information of each cabin component is directly linked to it and, based on the proof of concept presented, can be accessed intuitively. In addition, the complexity of the systems and the interdependencies beyond the system boundaries are visualized (see Fig. 8). Interaction with the virtual cabin improves understanding of the interrelationships of the respective systems and makes them easier to comprehend. The method shown for modeling cabin systems with a link to virtual reality is one step towards the goal of a complete digital twin. Future developments include usability tests in order to further research the integration of the human through VR in the conceptual cabin design



a) Study case 1: Distance measurement to the individual air outlets.

b) Study case 2: Distance measurement to the individual air outlets.

Fig. 9. Accessibility analysis of the service functions for the two layout cases.

process. Therefore, the next step is to investigate how the information gained from the virtual environment can be fed back into the conceptual design process in order to close the feedback loop. In addition, the cabin design algorithm will be extended to include other systems and the use of different materials for a more realistic representation will be investigated.

5. Conclusions

This publication described the procedure for the methodical design of aircraft cabin systems and the subsequent data transfer to virtual reality. The aim is to exploit unused potential in the cabin with new technologies through functional synergies. Therefore, the complexity must be understood and simplified in order to increase the potential in the cabin in terms of comfort, safety and eco-efficiency. Therefore, a virtual end-to-end system capability is needed where the entire supply chain is connected including the experts. For this purpose, a baseline for virtual development platform was created to test new concepts in a flexible and modular manner and to visualize the knowledge interactively.

A model-based approach was used for an automated layout of the cabin and its systems. The high-fidelity models used were built on the basis of simple assets, design parameters, and formalized knowledge. By exporting the generated data of the models, an interactive cabin model was created in virtual reality. The procedure was exemplified by the design of two different layout cases for the overhead storage compartment and the passenger service functions. Overall, the developed method shows many advantages, like fast reconfiguration and detailed evaluation, for the preliminary design and contributes to the aim of a digital cabin. The developed data structure ensures that all the necessary information from the conceptual design process pass through to the visualization in the VR. Connections and dependencies between the systems can be traced. The user can visualize these and can interact with the systems in virtual reality to process complex systems architectures. In addition, the object-oriented approach facilitates changes to the program code and enables extensions of rules or system dependencies in a modular way.

This research report presented a methodology for developing cabin systems which fits the purpose for traceability, digitization, and automatic reconfiguration. The study of the passenger service functions was a first demonstration of modeling a complex system. It was shown that connections can also be drawn beyond the system boundaries and that upscaling to the entire cabin system is thus possible. In the next step, the layout of the cabin systems will be extended to include additional concept cases and technologies. Furthermore, the connection to external data formats will be further extended and the possibilities in the virtual environment will be improved. This includes a multi-user functionality. That will enable several interdisciplinary teams of experts to participate in the conceptual development and evaluation of new cabin designs simultaneously and to share their ideas directly in the virtual reality. So, teams can act independently in their domain as well as in a larger network through the connection to the immersive environment. By developing new functions in VR, like grabbing and re-placing of the cabin elements, new cabin system layouts can be created as well. Then, the new position data can be exported and fed back into the design process. Subsequently, the new system architecture can be examined for compliance with the requirements and the results can be automatically transferred to the virtual environment for a new review. The planned closed conceptual design process loop accomplish data consistency and contributes to the achievement of an end-to-end digital system capability.

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Author statement

We hereby confirm that all authors have seen and approved the final version of the revised manuscript. We warrant that the article is the original work of the authors, that it has not yet been published, and that it is not under consideration for publication elsewhere.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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