Deliverable D 8.1
Basic Design Concept Proposal Vessel Variants

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1 Executive Summary

This deliverable (D8.1) presents the results of Work Package 8 (WP8) within the Pods4Rail project, focusing on the development of modular and flexible Transport Unit (TU) design variants. The aim was to establish a scalable design framework accommodating both passenger and cargo transport while adapting to diverse operational conditions and route topographies.

A systematic methodology combining requirement analysis, technological research, and Morphological Analysis was applied. Key TU parameters – including size, materials, seating, HVAC, doors, and structural components – were identified and organised in a morphological box, enabling exploration of multiple design combinations. Morphological paths for use cases (UC1, UC2, UC8, UC18) were defined, leading to the derivation of five main design variants (DEV-A to DEV-E) covering metal, composite, bio-based, wood, and steel constructions.

Major findings indicate that modularity allows adaption across several use cases (public passenger, premium passenger, etc.), PRM compliance requires at least a 10 ft unit for full accessibility. For cargo transport, besides standardized 10 ft and 20 ft ISO containers, 5 ft TU units could be developed specifically for the Pod system, enabling flexible storage solutions and efficient small-unit handling.

Recommendations emphasize leveraging modular plug-and-play components for adaptive interiors and selecting materials based on a balance of sustainability, manufacturability, and operational requirements.

Limitations include the need for further validation, particularly regarding production feasibility, lifecycle performance, and cost optimization. Despite these constraints, the methodology provides a traceable framework for future TU development and intermodal transport solutions.

2 Abbreviations and Acronyms

Abbreviation / Acronym	Description
CBA	Cost-Benefit Analysis
CCTV	Closed-Circuit-Television
CU	Carrier Unit
DEV	Design Variant
ESG	Single-pane Safety Glass
HMI	Human-Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Organization for Standardization
PRM	Persons with Reduced Mobility
TU	Transport Unit
TSI	Technical Specification for Interoperability
UC	Use Case
V2X	Vehicle-to-everything
VSG	Laminated Safety Glass
WP	Work Package
WS	Work Stream

3 Background

The Pods4Rail project is clustered into three Work Streams (WS) (Figure 1). The WS1 contains of five WPs dealing with the "Identification of use cases, business cases/CBA, operational concept." The WS2 also contains of five WPs dealing with the "Moving Infrastructure vessel and operation system". Finally, the WS3 comprises three WPs dealing with "Moving infrastructure carrier incl. locking system and handling system".

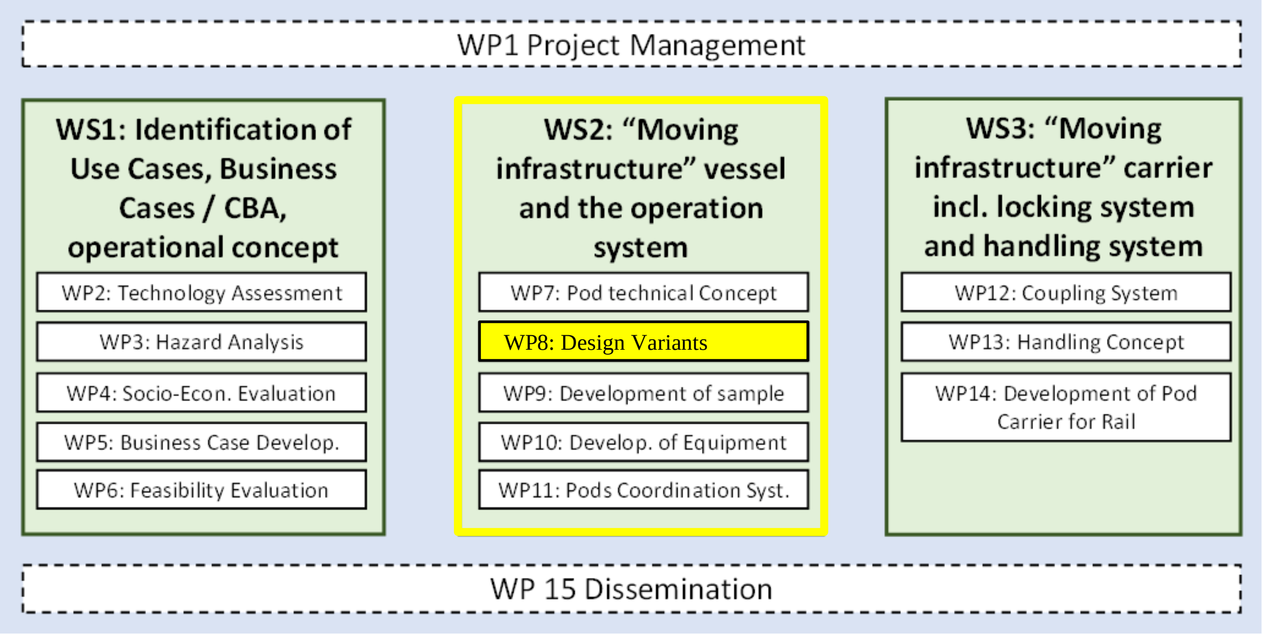

Figure 1: Pods4Rail work streams

The work reported in this deliverable has been performed within Work Package (WP8) "Design variants of the vessel" as part of WS2 "Moving infrastructure vessel and the operation system".

The present document summarizes the results of D8.1 Basic design concept proposal vessel variants, within the framework of the flagship project of Area 7, Pods4Rail, as described in the EU-RAIL MAWP.

4 Objective/Aim

The objective of WP8 is to develop and assess flexible and modular Transport Unit[1] (TU) design variants that enable container-based transport solutions tailored to the predefined use cases (UC). The central aim is to establish a scalable and versatile design framework that accommodates both passenger and cargo transport while considering heterogeneous route topographies and operational conditions.

To achieve this, WP8 will systematically derive TU design variants that reflect a comprehensive spectrum of transport requirements. This includes the joint transport of passengers and goods within one standardized Pod system as well as specialized variants optimized for particular operational scenarios. For this, the WP8 builds on previous WPs (especially WP2, WP4 and WP7).

The outcome of WP8 will be a set of visualised and technically validated Transport Unit variants that provide a structured basis for subsequent technical detailing in WP9 "Development of sample vessel" and WP10 "Development of Equipment". By integrating operational, logistical, and infrastructural constraints into the design process, WP8 ensures that Transport Unit design concepts are not only technologically feasible but also adaptable to future multimodal transport systems.

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[1] The Grant Agreement (GA) uses the term "vessel". However, we will use "Transport Unit" instead of "vessel" because this is the term defined in WP2: "Transport Unit: The Transport Unit (for passengers and/or freight) includes the safe carriage of passengers or goods, as well as the functionalities that ensure their comfort and safety during transport. It does not include other concepts considered in this deliverable, such as handling systems and operating systems".

5 Analysis and Research of Requirements for Design Variants

The objective of this chapter is to determine TU design requirements (and herein named parameters) of the predefined UC. Therefore, on the first hand, the predefined UC are shown and respective requirements regarding layout and equipment of each TU is given, based on previous WP7 (chapter 5.1). On the second hand, an overview of materials, design methods and joining technologies is given to analyse possible design technologies for the defined TU (chapter 5.2).

5.1 Overview of Transport Unit Requirements for Design Variants

The following four UC are analysed in more detail. A full description of each UC can be found in D4.1 [Pods4Rail D4.1., 2024]

UC 1: Basic public passenger transport

- UC 2: Premium public passenger transport
- UC 8: Persons with reduced mobility (PRM) applications (10 ft)
- UC 18: Container transport (5 ft, 10 ft and 20 ft)

Each requirement is grouped into these categories. The requirement of each UC is taken from [Pods4Rail D7.1. ,2024] [Pods4Rail D4.1. ,2024]

Purpose: The main purpose of the TU.

- Focus: Design focus as input for user friendly and needs oriented design strategy.
- Design elements: Key elements for interieur/exterior TU design.
- Main equipment: List of equipment, that should be integrated into the TU.
- Accessibility: Location and type of door technology and assisting equipment to access the TU.
- Dimensions: Size of the TU (5 ft, 10 ft or 20 ft).

UC 1: Basic public passenger transport

UC 1 focusses on cost-effective passenger transport with high capacities and standardised workflows. Therefore, the TU design and equipment is based on standard materials and equipment, as it is known in public transport on road and rail. With this approach the TU fits to a high percentage of users and can be produced and integrated into existing businesses.

- Purpose: Transport of relatively high number of passengers in public transport service operation over short distances.
- Focus: Cost-effective design, high capacity, and functional interiors (comparable to city busses).
- Design elements: Standard seating arrangements, minimal comfort features, easy maintenance.
- Main equipment:
    - Interieur: up to 12 standard seats (for sitting configuration), handrails, standard passenger information system, stop buttons, door buttons, air conditioning (HVAC system), small luggage storage, emergency equipment, standard materials (such as steel, aluminium, plastics, textiles), lighting.
    - Exterior: Passenger information system, door buttons, doors, automation sensors, mechanical and electrical interfaces, standard materials (see chapter 5.2).
    - Structure and others: Vehicle body structure, batteries, electronic control units, simple insulation materials (sound, vibration, temperature).
- Accessibility: Every TU is equipped with at least two standard low floor doors (left/right side or front/rear). No additional assisting technology is needed.

- Dimensions: 10 ft TU for sitting configuration (up to 12 seats), 20 ft TU for standing configuration (up to 50 passengers).

UC 2: Premium public passenger transport

UC 2 addresses more comfortable public transport solutions. Therefore, the main TU layout is still based on public transport standards, but increased equipment quality can reach more comfort and options for individualisation. Less low-cost requirements and less mass production open new possibilities in sustainable TU design and choice of materials.

- Purpose: Transport of small number of passengers in public transport service operation over short or longer distances with higher comfort and individualisation as well as sustainability options.
- Focus: Enhanced passenger experience, comfort, and additional amenities (comparable to shuttle cars or first-class train cabins).
- Design elements: Reclining seats, entertainment systems, premium materials.
- Main equipment:
    - Interieur: 2-6 spacious reclining seats, hand rests, passenger information and infotainment system, stop buttons, door buttons, HVAC, bigger luggage storage, emergency equipment, advanced materials (such as aluminium, bioplastics, textiles or wooden components), lighting.
    - Exterior: Passenger information system, door buttons, doors, automation sensors, mechanical and electrical interfaces, standard materials (see chapter 5.2).
    - Structure and others: Vehicle body structure, batteries, electronic control units, advanced insulation materials (sound, vibration, temperature).
- Accessibility: Every TU is equipped with at least two standard low floor doors (left/right or front/rear). No additional assisting technology is needed.
- Dimensions: 5 ft or 10 ft TU for individual configuration.

UC 8: PRM applications

UC 8 specifically addresses barrier-free transport of people and their assisting devices or persons. Therefore, the manufacturing numbers are less and individualisation as well as comfort for this user group can be maximised. Also, sustainability and comfort can be focussed on the choice of materials and design in order to create a positive travel experience.

- Purpose: Barrier-free transport of people with reduced mobility (PRM) with wheelchairs, strollers or elderly etc.) with spacious layout and high degree of assisting services and comfort.
- Focus: Accessibility and inclusivity for passengers with reduced mobility.
- Design elements: Wheelchair access, adjustable seating, assisting technologies.
- Main equipment:
    - Interieur: 2-6 spacious adjustable seats, handrails at seats, doors and aisle, barrier-free passenger information system, stop buttons, door buttons, air conditioning, spacious storage area for strollers / wheelchair etc. With securing devices, emergency equipment, advanced materials (see above), optional: additional sanitary module (toilet, sink, bio reactor, etc., reduces the available space / number of passengers).
    - Exterior: barrier-free passenger information system, door buttons, doors, automation sensors, mechanical and electrical interfaces, standard materials (see chapter 5.2).
    - Structure and others: Vehicle body structure, batteries, electronic control units, advanced insulation materials (sound, vibration, temperature).
- Accessibility: Every TU is equipped with barrier-free low floor doors at each side (left/right). Additional assisting technology, such as electrical ramp, is needed. The TU is equipped with an integrated lifting device (one in each corner) so that the carrier unit (CU) can place the TU on the ground.
- Dimensions: At least a 10 ft TU for barrier-free configuration is needed.

UC 18: Container transport (5 ft, 10 ft and 20 ft)

UC 18 addresses general freight transport with ISO-Containers. Because of that, standardised interfaces are foreseen. The equipment depends on the specific freight containers. This includes, for example, classic ISO-containers without additional equipment, but also containers with special tasks (e.g. refrigerated containers). Due to the different requirements for each individual container (5, 10 and 20 ft) but also its individual area of use, the interior equipment cannot be answered in general terms.

- Purpose: Transport of any kind of freight in standardised containers.
- Focus: Efficient cargo handling for standard container sizes.
- Design elements (optional): Modular cargo storage, secure fastening systems, scalability for hybrid use.
- Main equipment: None. Depends on the freight use case.
- Accessibility: Standard container doors without additional devices.
- Dimensions: 5 ft, 10 ft and 20 ft.

Entrance/exit unit

Rail CU share a standardised design and can be flexibly configured with different types of TUs). In passenger and hybrid (people and goods) transport configurations, at least one entrance/exit module is integrated to provide access and ensure connectivity between adjacent TUs and external platforms. This unit offers doors on both sides (left and right) as well as at the front and rear, enabling smooth transitions between neighbouring TUs and efficient boarding and alighting from the outside platform. In cargo transport configurations, the carrier may be equipped exclusively with freight modules and thus not require passenger access.

The primary role of the entrance/exit module is boarding and alighting, as well as acting as a transitional interface between passenger transport modules. The unit serves as a transfer point for luggage and allows loading and unloading of micro-cargo, such as parcels for last-mile delivery or bins for food-delivery. A dynamic passenger information system displays connections and route optimization, it acts as a smart city interface, exchanging traffic, tourism, and emergency data. It provides interactive guidance through AR, touch panels, or voice assistants.

However, passengers may also remain in this unit during travel, especially when standing, waiting, or with luggage.

- Purpose:
  - Primary functions: Entrance and exit area for passengers, as well as transitional interface between neighbouring TUs and platforms.
  - Secondary functions: Access control, security screening, passenger flow management, micro-cargo handling (parcels, food delivery), dynamic passenger information, interactive guidance.
- Focus: Low floor accessibility for every passenger, no comfort equipment.
- Design Elements: Doors on each side, entry assisting technologies.
- Main equipment:
  - Interieur: Handrails, lighting, minimal passenger information system, door buttons, emergency equipment, standard materials (see above), optional: storage area for luggage or on-board equipment.
  - Exterior: minimal passenger information system, handrails, door buttons, mechanical and electrical interfaces, standard materials (see chapter 5.2).
  - Structure and others: Simple vehicle body structure, no special equipment.

- Accessibility: Every TU is equipped with standard low floor doors at each side (left/right) and aisle doors at front and rear. Additional assisting technology, such as electrical ramp or stairs can be used, if needed (based on the CU design). For PRM we select UC 8 [Pods4Rail D4.1., 2024]].
- Dimensions: 5 ft entrance/exit unit.

Standard requirements for every TU
Besides each UC-specific equipment, a standardised set of interface-technology is needed for every TU. Especially the mechanical and electrical couplings must be integrated into each TU at its specific location. Additionally, to that, communication components, electronic control units and energy equipment, such as batteries, charging adapters and charging devices, must be installed, but these components are not necessarily exposed to the exterior.
Another requirement for every passenger TU is a door-window-wall balance, which means that the existence of doors and windows must be balanced with closed wall structures according to the UC to enable a good user experience. Also, it is necessary to install safety and emergency equipment to every passenger TU, such as fire extinguishers, emergency exit devices, panic buttons, communication devices etc. Even though these elements are needed for the final TU design, they are not influencing the general TU layout in this stage. Another general requirement is automation technology, such as optical or acoustic sensors to detect the surrounding. A full set of functional requirements was analysed in D4.4 [[Pods4Rail D 4.4., 2024] and can be reviewed there. Specific safety relevant requirements were assessed and concluded in D3.2. [Pods4Rail D3.2. (2024).]

5.2 Overview of Possible Materials, Design Methods and Joining Technologies

Various materials, design methods and joining technologies must be considered for the development and construction of the TU. Depending on the global requirements (such as lightweight design, damping behaviour and formability), there are UC-specific properties that the design method, the material or the connection technology must have. This is the only way to ensure that the TUs can be designed in accordance with the requirements and framework conditions identified in the previous WPs. In addition, requirements are placed on the various interfaces to carriers, other TUs and the equipment. Different criteria are of varying importance for each UC. The suitable materials, design methods and joining technologies are summarized in the following tables.

The tables (can be found in the Appendix A) are structured as follows:

- 1st column: designation and assignment, if appropriate
- 2nd column: short description
- 3rd and 4th column: the main advantages and disadvantages, based on the underlying purpose of the TU design the same person.
- 5th column: area of application or suitability (e.g. load bearing / non-load-bearing structures, cladding, large or small series)

No evaluation is made at this point. It merely provides an objective overview of which technology is possible.

Table 2 (10.2 Appendix B) shows possible materials that can be used for load bearing and, above all, non-load-bearing areas. Material groups are primarily mentioned, but not precise details. For example, wood is not subdivided into different types of wood but characterized in general terms. The same applies to alloys for metals or core materials for sandwich materials. If every alloy would be considered, this would lead to countless possible materials and is not the aim of this WP. The table focuses primarily on the individual material group and their suitability. The last two lines (composites and sandwich materials) are semi-finished products and not classic materials, but are nevertheless included in this table, as they are widely used as materials in various combinations and a deliberate distinction is to be made here from the design method, in which the sandwich design method is taken up again.

Table 3 (10.2 Appendix B) shows possible design methods. The general design methods are described here and not the manufacturing technologies. These can then be examined more specifically when selecting the appropriate design method. This means, for example, that the manufacturing technology "extrusion" can be found in the design method "integral design". 3D printing is also considered as a design method independent of the multitude of possible processes such as powder bed printing or fused deposition modelling.
These design methods can be divided into three main categories, which are highlighted in the table in different colours:

1. Differential design: design method consisting of many individual pieces that are put together.
2. Integral design: Production of the end product from as few pieces as possible.
3. Multi-material design: design method using different materials, in which the material properties are utilized in a targeted manner and the material is used with the corresponding design method in such a way that the functional requirements are met in the best possible way.

The joining technologies are divided into three groups:

- Inseparable joining
- Conditionally detachable joining
- Detachable joining

Based on this overview, a design selection can then be created and evaluated specifically for each TU and UC in the following chapters. It is not one material or one design that is ideal, but it is important to consider which requirements are necessary or desirable at which point. A combination of different options makes the best product possible. At the same time, however, external boundary conditions such as ecological and economic evaluation parameters must also be considered. It is not enough to simply cover the technical requirements with the materials, design methods and joining technologies presented. In the next chapter, the UC is specified, based on which the above-mentioned materials, design methods and joining technologies are then selected.

6 UC-specific Transport Unit Design Variant Goals

The relevant parameters at the main component level (i.e., at the functional level of the TU) were systematically identified using a combined methodological approach based on established concepts from design research, systems engineering and engineering sciences.

Initially, a requirements-based derivation of the parameters was carried out. This considered the defined specific UC, payload cases, and normative requirements from WP4, WP7 and the ongoing work in WP5 [Pods4Rail, D 4.1] [[Pods4Rail, D 7.1]. The resulting design requirements are presented in Chapter 5.1, “Overview of Transport Unit Requirements for Design Variants.” Based on this, the key functional requirements for the main components of the TU were defined.

In parallel, technological desk research was conducted to identify suitable design methods, joining techniques, and materials. The results are summarised in Chapter 5.2, “Overview of possible Materials, Design Methods and Joining Technologies.” This survey provided the basis for deriving parameters related to materials, structure, and joining technologies that influence form, functionality, and performance of the main components.

6.1. Method: Morphological Box

Morphological Analysis in the Context of Transport Unit Design
Building upon the previously identified and elaborated parameters – covering functional, structural, configurational, and symbolic aspects – morphological analysis is applied as a systematic method to explore the full design space of the Transport Unit (TU) (Zwicky, 1969; Ritchey, 2006). This approach enables the structured combination of parameter attributes, ensuring that both technical feasibility and user-centred considerations are integrated into potential design variants.

Systematic Structuring of Design Parameters
Central to this method is the morphological box, in which each row represents a parameter and each column lists its possible attributes. The box provides a visual and analytical framework for systematically combining attributes across parameters. By traversing the box along selected sequences of attributes, a morphological path is defined, representing a coherent set of design choices that collectively constitute a TU design variant (see 10.2 Appendix B).

6.2 Description of Parameters of TU Design Variants

For each identified parameter, multiple attributes were defined. These attributes were then organised in a morphological box to systematically explore different combinations (Zwicky, 1969). By iterating through these combinations, a wide range of TU design variants could be generated, addressing both functional requirements and technological constraints.

This methodological approach (Friedenthal et al., 2014) ensures a systematic, traceable, and comprehensive identification of relevant parameters, forming the foundation for subsequent design development in WP9.

What are Parameters?

In the context of TU design, parameters are defined as quantifiable or categorisable aspects of a system that can influence its form, functionality, performance, and user experience (Ullman, 2010; Pahl et al., 2007). Parameters can relate to physical dimensions (e.g., container size), structural characteristics (e.g., material, joining technology), functional attributes (e.g., seating configuration, HVAC type), or technological components (e.g., sensors, HMI systems).

By defining parameters and their possible attributes, all feasible combinations of design choices can be systematically explored. This ensures that no relevant design alternative is overlooked, enabling a thorough assessment of functionality, manufacturability, and cost (Zwicky, 1969). It should be noted that the parameters are highly interdependent with the requirements and technologies previously defined in Chapter 5.

Parameters are not merely descriptive elements but strategic design levers that enable a structured, reproducible, and comprehensive approach to developing TU variants that satisfy all functional and technological requirements.

Table 1: Identified Parameters and Attributes

Parameter	Attributes
Size	5 ft, 10 ft, 20 ft, Other
Seats	<10, >10, None
Seat design	Classic textile seat, Standing/leaning seat, Premium seat, First-class aviation seat (reclining/sleeper seat), Moulded plywood single (tram seat), Foldable seats
Seating configuration	Lateral, medial, face-to-face, turnable
Wheelchair space	Yes, No, Additional space for stroller
HVAC	Full, Heating/ventilation only, Ventilation only (forced), Ventilation only (free – window open), None
Entrance/exit location	Front, Rear, Front and rear, Side, Both sides, All four sides
Door type	Inward swing, Outward swing, Sliding, Double-leaf sliding, Folding, Roller shutter, Gull-wing
Windows	Side wall (full format), Side wall half, Only front/rear, Bull's-eye, No windows, Artificial interior lighting
Window functionality (opening)	Yes, No
Window material	Flat glass (ESG), Composite glass (VSG), Polycarbonate, Smart glass
Structural material (carbody)	Steel, Aluminium, Magnesium, Wood, Carbon fibre, Glass fibre, Polymers, Flat textiles, Leather, Glass, Composite, Sandwich (see Chapter 5.2)
Production technology (carbody)	Manual welding, Laser welding, Friction stir welding, Spot welding, Gluing/adhesives, Flow-drill screws, Rivets, Screws, Plug, Clipping, 3D printing (see chapter 5.2)
Design method	Differential design, Skeleton, Shell, Frame, Integral, 3D printing, Monocoque, Multi-material, Sandwich (see Chapter 5.2)
Interior materials (main components)	Steel, Aluminium, Magnesium, Wood, Carbon fibre, Glass fibre, Polymers, Flat textiles, Leather, Glass, Composite, Sandwich (see Chapter 5.2)
Exterior materials (main components)	Steel, Aluminium, Magnesium, Wood, Carbon fibre, Glass fibre, Polymers, Flat textiles, Leather, Glass, Composite, Sandwich (see Chapter 5.2)
Manufacturing volume	High (> 10,000 pcs/year), Medium (1,000–10,000 pcs/year), Low (< 1,000 pcs/year)

Methodological Approach

A methodological approach is required to take parameter interactions into account. In WP8, the participants selected the following approach in accordance with the explanations above:

1. Parameter definition: All main components of the TU were analysed in terms of function and influencing factors.
2. Attribute assignment: Realistic options for each parameter were determined based on requirements, standards, materials, and manufacturing technologies.
3. Combination exploration: Using the morphological box, all attributes were systematically combined to generate different Transport Unit design variants.
4. Variant evaluation: The generated variants can be evaluated according to functionality, space utilisation, material requirements, production technology, cost, and user comfort, based on the specific requirements of the selected UC.

Each parameter is then detailed with its possible attributes and combined in a morphological box to generate different TU design variants.

6.3 Complexity of Design Features

The complexity of design possibilities in TU development arises from the multidimensional nature of the relevant design parameters identified in Chapter 6.2 (see Table 1). These parameters, understood as variables that directly influence the form, functionality, and perception of the Transport Unit (TU), form the conceptual bridge between use case (UC) requirements and technical realisation within the overall engineering process (Pahl et al., 2007; Ulrich & Eppinger, 2015).

At the starting point of this complexity lies the intended UC, which fundamentally defines whether the TU is designed for passenger transport, goods transport, or a mixed configuration. Each UC introduces a distinct set of functional and regulatory requirements that shape the subsequent design space. For example, passenger-oriented UCs require parameters related to seating arrangements, HVAC systems, accessibility, and safety features, whereas goods-oriented UCs prioritise volumetric efficiency, structural robustness, and material handling compatibility (Ullman, 2010). Mixed-use UCs further increase complexity by requiring trade-offs between these competing requirements.

Based on the parameter set defined in Chapter 6.2, the functional design parameters relevant to these purposes can be grouped into different categories:

1. Structural parameters that define the physical architecture, load-bearing capability, and production feasibility of the TU (e.g. size, structural material (carbody), design method, production and joining technologies).
2. Functional parameters that directly influence the operability and user experience (e.g. seating design, HVAC configuration, door type, window functionality, sensor integration).
3. Configurational parameters that determine spatial flexibility and adaptability to different UCs (e.g. seating configuration, entrance/exit location, overall interior layout).
4. Perceptual and experiential parameters that shape the subjective user perception, comfort and acceptance of the TU (e.g. window size and type, interior materials, lighting concepts, HMI systems).

The overall complexity of TU design arises from the interdependencies between these categories: altering one parameter often affects others. For example, the choice of a lightweight composite material may reduce overall weight and increase payload capacity, but it may also necessitate a different joining technology and influence thermal or acoustic performance. Similarly, the integration of advanced HMI systems increases user comfort but may also require changes in energy management and system interfaces (Friedenthal et al., 2014).

6.4. Morphological Paths

From Parameter Combinations to TU Design Variants (DEV)

Within the context of the project, morphological paths were generated for four specific use cases (UC1, UC2, UC8, UC18). For each UC, the corresponding path illustrates which combination of parameter attributes is most appropriate given the operational requirements, user needs and technological constraints. This allows for explicit documentation of the rationale underlying each TU variant and supports transparent evaluation of trade-offs between technical performance, functionality and symbolic meaning.

The analysis of these morphological paths enables the derivation of conclusions for TU design development, including:

- Identification of key parameter combinations that satisfy UC-specific requirements.
- Recognition of parameters that drive differentiation across different UCs.
- Support for iterative refinement in WP9, ensuring that selected TU variants are robust, adaptable, and aligned with user expectations.

Morphological methods such as morphological analysis, the morphological box, and morphological paths provide a structured and traceable approach for systematically exploring the multidimensional design space. They establish a direct link between the definition of relevant parameters and actionable design decisions. In particular, the morphological box enables the identification of key characteristics of potential solutions as well as multiple options per parameter, which are then represented in a matrix. This process generates and evaluates a wide range of solution options. The method increases development efficiency by reducing effort and supporting the identification of robust and reliable design solutions.

From morphological paths (see 10.2 Appendix B) different design variants (DEV) were derived and described in more detail in the following chapter.

6.5. Identified Design Variants (DEV)

DEV-A: Metal Lightweight Design

The DEV-A design variant (see 10.2 Appendix B, Table 4) relies on lightweight metal structures, typically using aluminium or high-strength steel alloys for the main framework and panels. This approach provides high structural integrity, predictable mechanical performance, and durability, making it suitable for the demands of a modular POD-system in both passenger and cargo applications.

Metals offer excellent load-bearing capabilities and can withstand repetitive stresses and vibrations encountered during multimodal transport. Assembly and maintenance processes are well established, and conventional joining techniques (welding, bolting, riveting) are readily available across global manufacturing sites (see Chapter 5.2).

However, metal-based design can be heavier than advanced composite alternatives, potentially reducing payload efficiency. Corrosion protection may be necessary in certain operational environments, increasing production complexity and cost. Nevertheless, the predictability, robustness and ease of repair make metal lightweight design a reliable baseline for TU development.

DEV-B: Thermoplastic Composites

The DEV-B variant (see 10.2 Appendix B, Table 5) uses thermoplastic composite materials, combining high-strength fibres (e.g., carbon or glass) with recyclable polymer matrices. This design enables significant weight reduction, improving energy efficiency and payload capacity within the POD-system.

Thermoplastic composites can be moulded into complex geometries, allowing the integration of functional features such as internal supports, cable channels, and attachment points directly into the structure. This supports modular assembly, as standardised modules can be prefabricated and joined with minimal additional hardware.

Challenges include higher production costs compared to metals, sensitivity to high-temperature processes, and the need for specialised tooling and manufacturing knowledge. Repair and recycling in some regions may also be more complex than conventional metal structures. The weight savings, design flexibility and potential for integrated functionality make thermoplastic composites an attractive solution for advanced TU variants.

In addition to conventional thermoplastic composites, bio-based thermoplastic composites offer the potential to replace carbon- or glass-fibre-reinforced plastics in certain Pod components. These materials combine renewable polymer matrices with natural fibres, reducing environmental impact while maintaining sufficient mechanical performance for non-structural or semi-structural applications.

For the TU, this could include interior panels, partitions, non-load-bearing structural elements and modular attachments, where extreme stiffness or high tensile strength is less critical.

Further investigation is needed to determine the optimal substitution strategy, balancing weight, strength, manufacturability, and cost. Key considerations include how bio-based composites perform under repeated loading, thermal cycling, and humidity exposure compared to conventional carbon- or glass-fibre composites. Identifying components where bio-based options are viable could enhance sustainability without compromising safety, durability or functional performance of the Pod system.

DEV-C: Natural Fibres for Sustainable Lightweight

Using laminated wood composites as the base material for the Transport Unit in DEV-C (see 10.2 Appendix B, Table 6) represents an intelligent, renewable and resource-efficient approach to lightweight design. Beyond weight reduction, this variant offers additional advantages: regional availability, low density combined with good mechanical properties, sustainable product life cycles and cost-effective utilisation.

Wood is a versatile, easy-to-process and durable material. When properly treated, it does not splinter, meets relevant fire safety standards and exhibits a long service life. Integrating wood-based materials enables sustainable product development with lightweight potential. Further investigation is recommended to assess how hybrid wood-based structures could be applied for lightweight design in the mobility sector, including railway, automotive and cable car applications.

In parallel, material and process-step simulations should be developed to efficiently control manufacturing processes and to identify raw material and process parameters at each step that significantly influence the defined functions of the component.

The use of regional and sustainable materials also emphasises the commitment to climate protection aligned with the European Union’s sustainability goals.

DEV-D: Steel Carbody

The steel carbody variant (see 10.2 Appendix B, Table 7) represents a conventional design method, widely used in the transportation industry due to its robustness, reliability and well-understood manufacturing processes. Steel offers high load-bearing capacity, impact resistance and durability, making it particularly suitable for structural components such as the frame, exterior panels and modular attachment points of the Transport Unit.

Conventional joining techniques, including welding, riveting, and bolting, are globally established and allow efficient assembly, maintenance and repair, even in regions with limited industrial infrastructure.

Steel-based construction also supports modular design, as standardised modules can be prefabricated and assembled on site. This facilitates parallel production processes, reduces lead times and enables straightforward replacement of damaged components, enhancing lifecycle sustainability. While steel is heavier than aluminium or composite alternatives, its predictable mechanical behaviour, comparatively low-cost and broad availability make it a reliable baseline solution for both passenger and cargo Pod variants.

The conventional steel carbody is therefore particularly advantageous when cost-efficiency, ease of repair, and operational robustness are prioritised over extreme lightweighting, making it an effective choice for high-volume or infrastructure-constrained applications.

Excursus: Analysis 5 ft PRM Unit

It was examined whether the 5 ft entrance unit could serve as a small PRM (Persons with Reduced Mobility) transport unit. However, this option is not feasible due to insufficient interior dimensions. To comply with TSI PRM requirements, a minimum wheelchair turning radius of 1,500 mm must be ensured (see Figure 2). A 5 ft unit does not provide enough space for this turning radius, nor for the additionally required safety and accessibility equipment.

Therefore, the 5 ft unit would need to be extended by at least 160 mm to meet the required turning radius and accessibility specifications, including a wheelchair space with minimum dimensions of approx. 750 mm × 1,300 mm, anchoring systems, an assistance seat, handrails and safety controls within reach and a clear door width of at least 800 mm (see Figure 3).
An accessible sanitary module is not mandatory for short-distance operations (e.g., shuttle transport). In a 10 ft PRM unit, such a module could be optionally integrated.

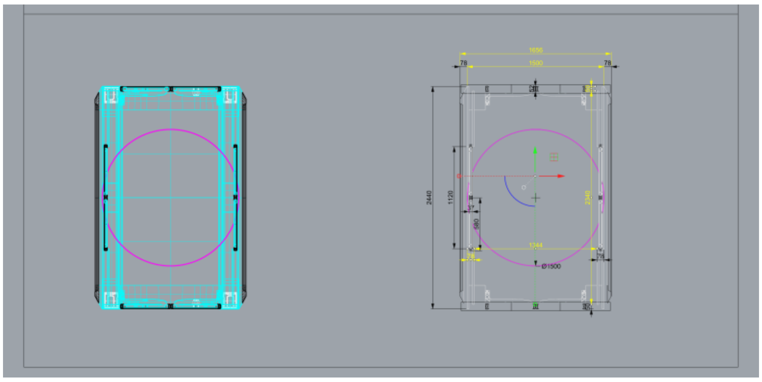


Figure 2: 5 ft PRM unit does not provide the required wheelchair turning radius

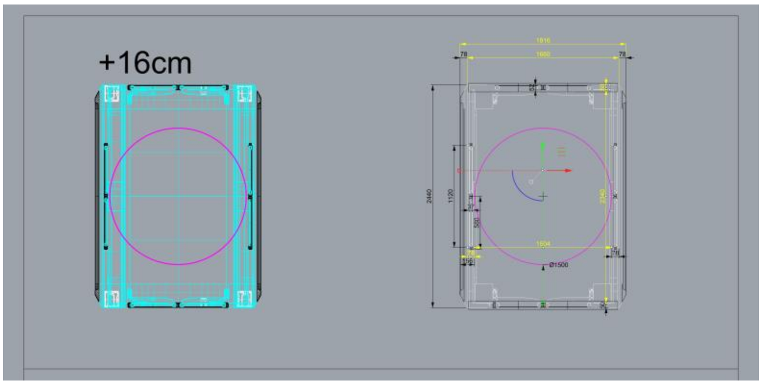
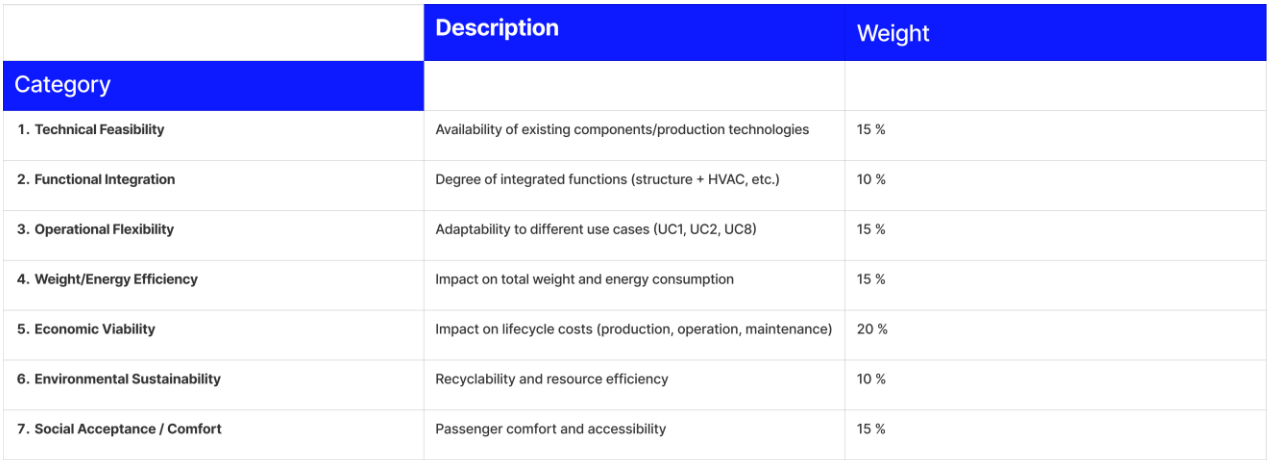


Figure 3: Wheelchair turning radius could be achieved by extending the unit by at least 160 mm

The concept of WP8 will use a 5 ft entrance unit for the PRM module. To fulfil TSI PRM standards, including wheelchair manoeuvrability, anchoring systems, assistance seating and optional sanitary equipment, a minimum internal length equivalent to a 6 ft unit is necessary, with 10 ft being the optimal size for full PRM accessibility including a sanitary module. However, this would require further detailed investigation.

6.6 Evaluation of Critical Paths (Chosen Design Path)

The morphological paths generated by project participants were systematically evaluated against seven pre-defined assessment categories: (1) Technical Feasibility, (2) Functional Suitability, (3) Economic Efficiency, (4) Safety & Reliability, (5) Maintainability & Modularity, (6) Environmental Sustainability, (7) Social Acceptance / Comfort. The project group collectively established the percentage weighting for each of the seven predefined assessment categories.



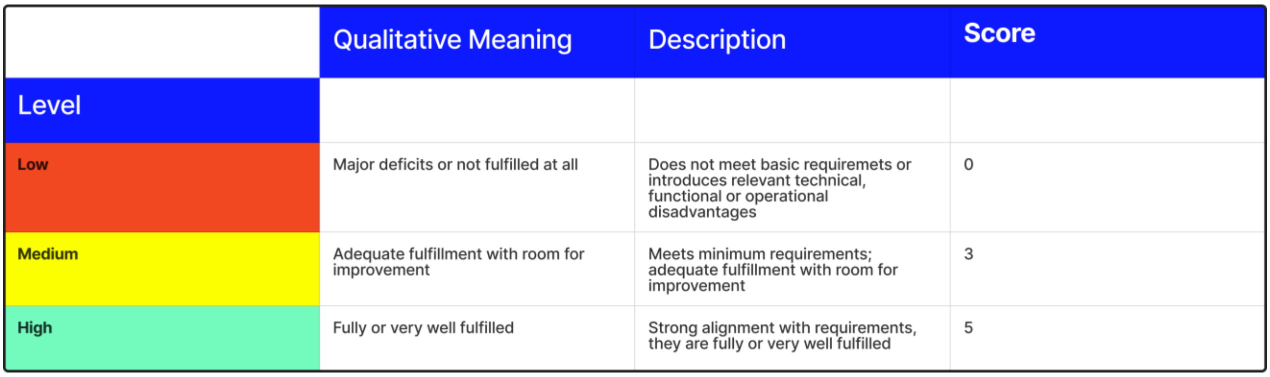
	Description	Weight
Category		
1. Technical Feasibility	Availability of existing components/production technologies	15 %
2. Functional Integration	Degree of integrated functions (structure + HVAC, etc.)	10 %
3. Operational Flexibility	Adaptability to different use cases (UC1, UC2, UC8)	15 %
4. Weight/Energy Efficiency	Impact on total weight and energy consumption	15 %
5. Economic Viability	Impact on lifecycle costs (production, operation, maintenance)	20 %
6. Environmental Sustainability	Recyclability and resource efficiency	10 %
7. Social Acceptance / Comfort	Passenger comfort and accessibility	15 %

Figure 4: Short description of assessment categories

Each path was independently scored by the experts of WP8 for each category in order to capture its strengths and weaknesses across technical, operational, economic and socio-environmental dimensions.

The scoring used a simple three-point qualitative scale (0/3/5), where “0“ denotes low suitability or negative impact, “3” denotes neutral or acceptable performance and “5” denotes high suitability or positive impact for the respective category (see Figure 4). This aggregated assessment profile enabled ranking of morphological paths, the identification of critical trade-offs (e.g. high technical feasibility versus low social acceptance) and the selection of candidate variants for further detailing during the next work packages.

Note: The scoring is carried out using expert assessment.



	Qualitative Meaning	Description	Score
Level			
Low	Major deficits or not fulfilled at all	Does not meet basic requiremets or introduces relevant technical, functional or operational disadvantages	0
Medium	Adequate fulfillment with room for improvement	Meets minimum requirements; adequate fulfillment with room for improvement	3
High	Fully or very well fulfilled	Strong alignment with requirements, they are fully or very well fulfilled	5

Figure 5: Three-point qualitative scale

7 Design and Visualisation of Alternatives

In Chapter 7, the derived DEV design will be explained in detail and visualised by using 3D renderings. Following figures are based on the results of previous Chapters 6.5, “Identified Design Variants (DEV)”.

The modular design (see ongoing WP9) and the design approach developed for UC1 (economy passenger transport) provides a flexible framework that can also be adapted for UC2 (premium passenger transport) as well as other UC (e.g. UC8: PRM application).

By defining standardised modules for main components – including door systems, roof/HVAC units, windows, exterior panels, side walls, seat structures, floor panels, interior partitions and anchoring points – different configurations can be combined within the same structural framework. This allows the TU to be customised for varying operational requirements or upgraded for premium applications (UC2) without the need to redesign the entire TU system. For example, seat modules can be replaced with more comfortable or adjustable options, interior panels can be upgraded with higher-quality materials, and layouts can be adapted to provide additional legroom or enhanced passenger amenities.

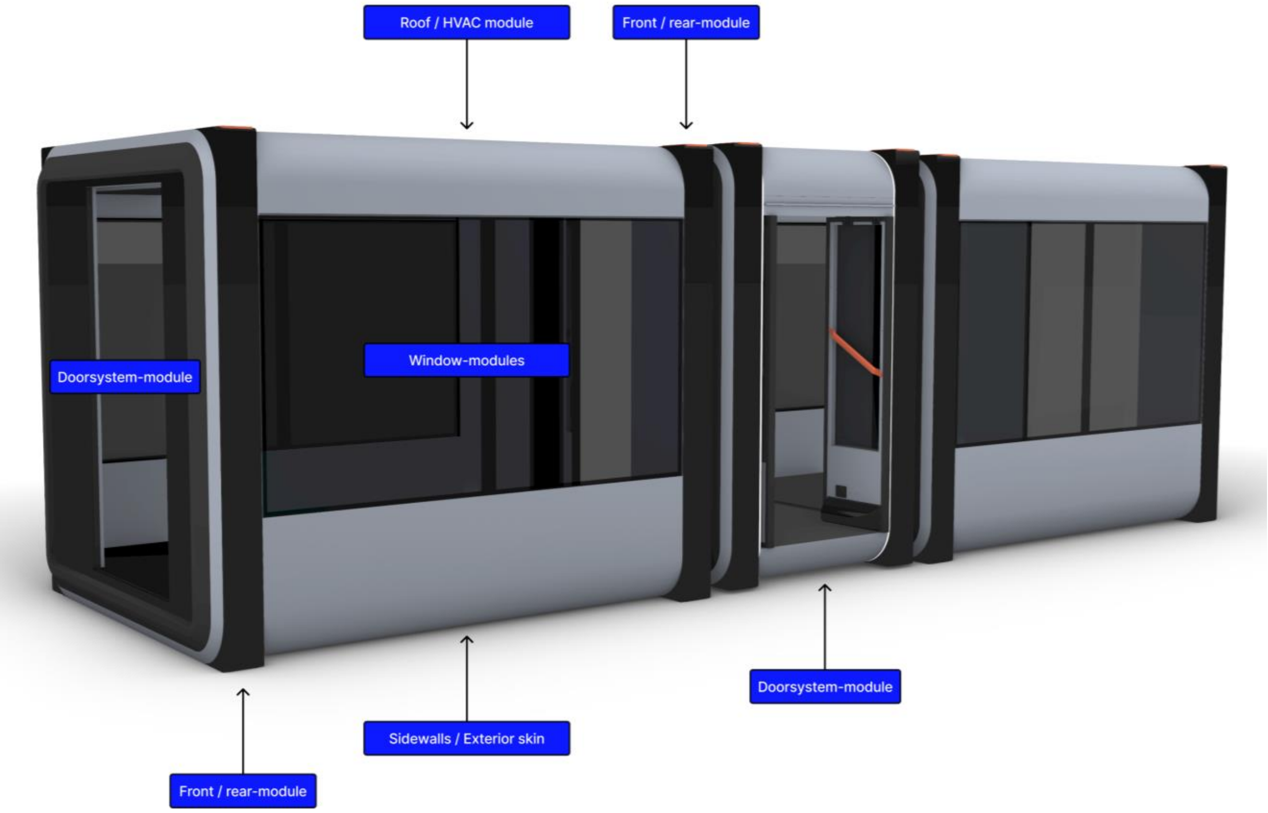


Figure 6: Overview of TU exterior modules. Standard configuration 10/5/10 with open entrance/exit doors in the entrance module. All details are simplified.

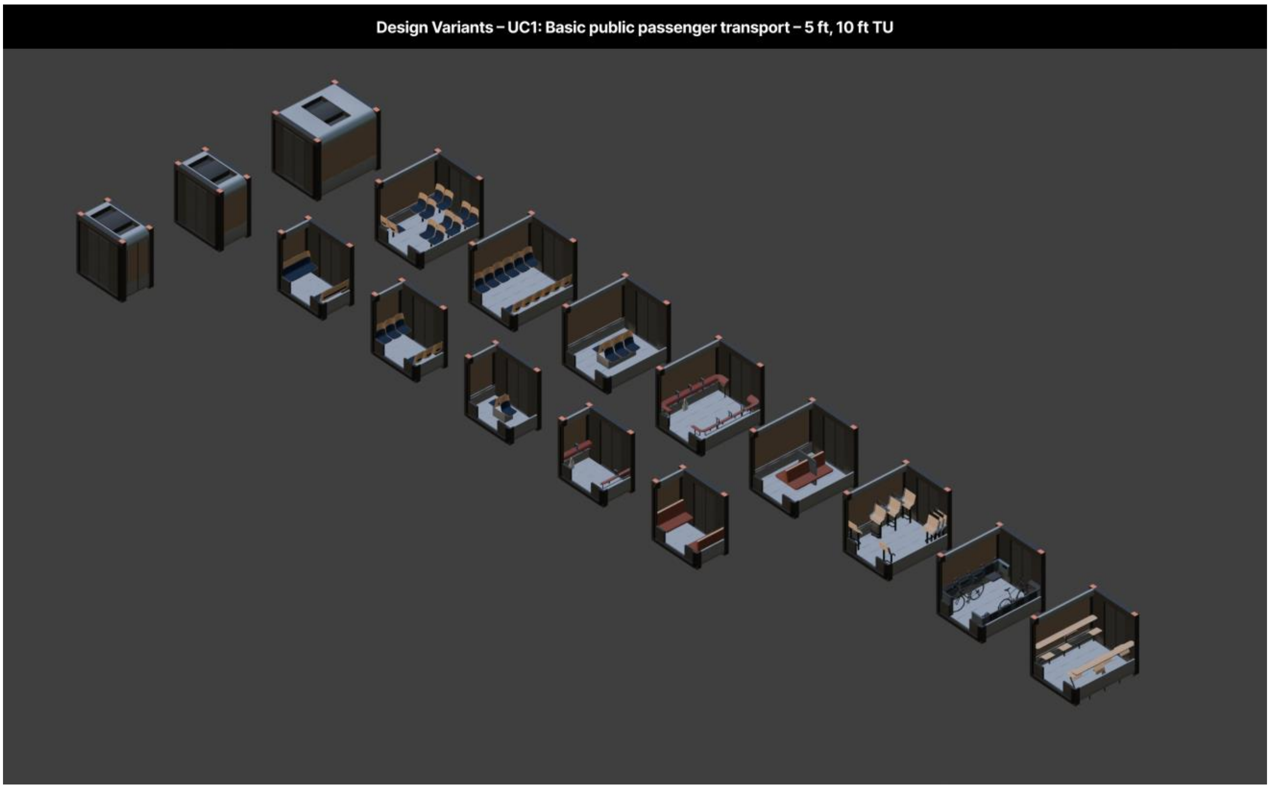


Figure 7: Overview of TU interior layouts for UC1 (© moodley)

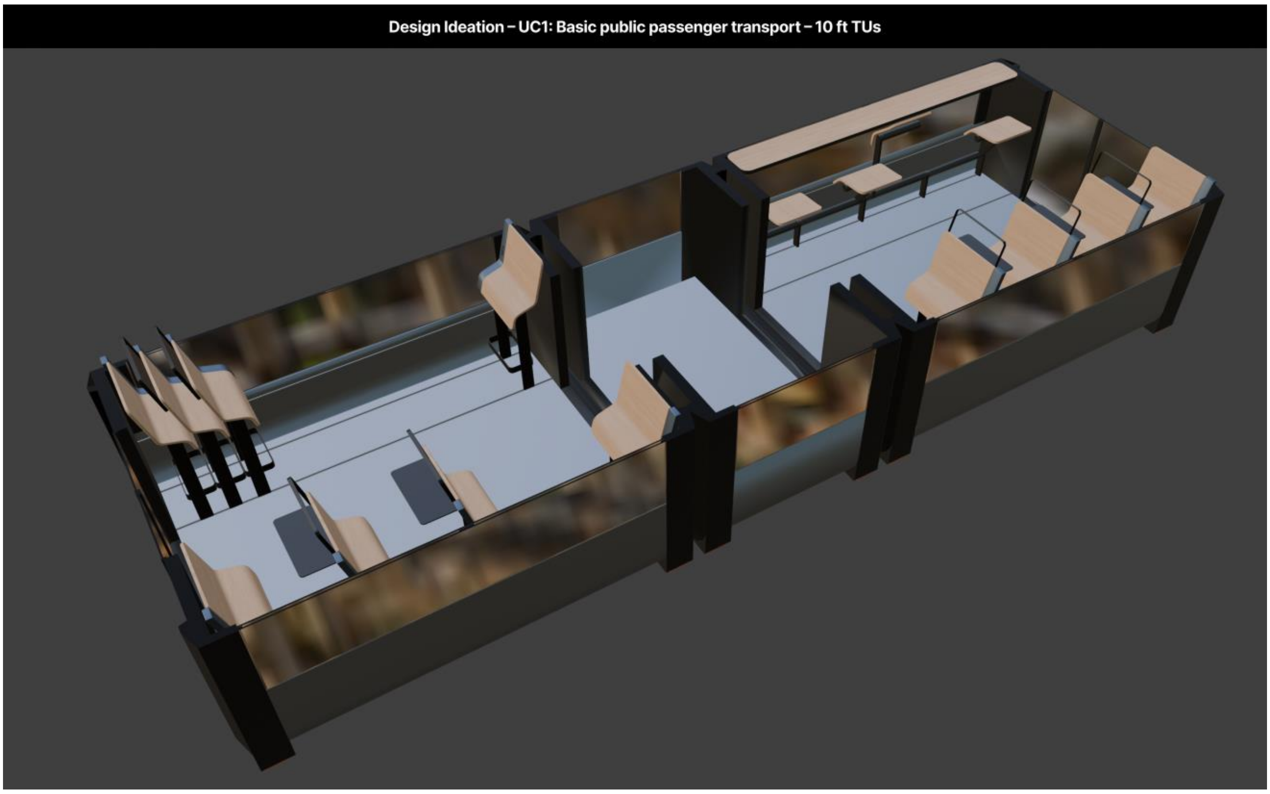


Figure 8: Mixed TU interior layout for UC1 (© moodley)

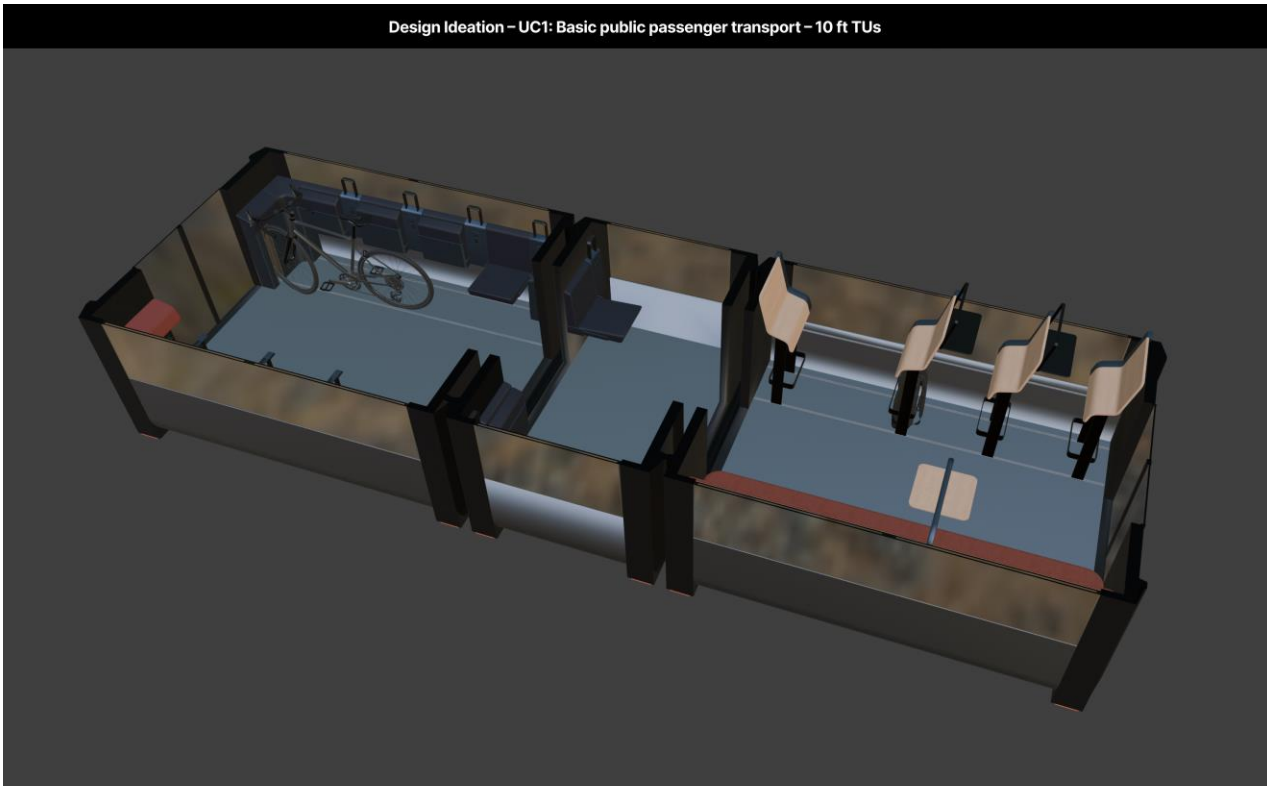


Figure 9: Mixed TU interior layout for UC1 (© moodley)

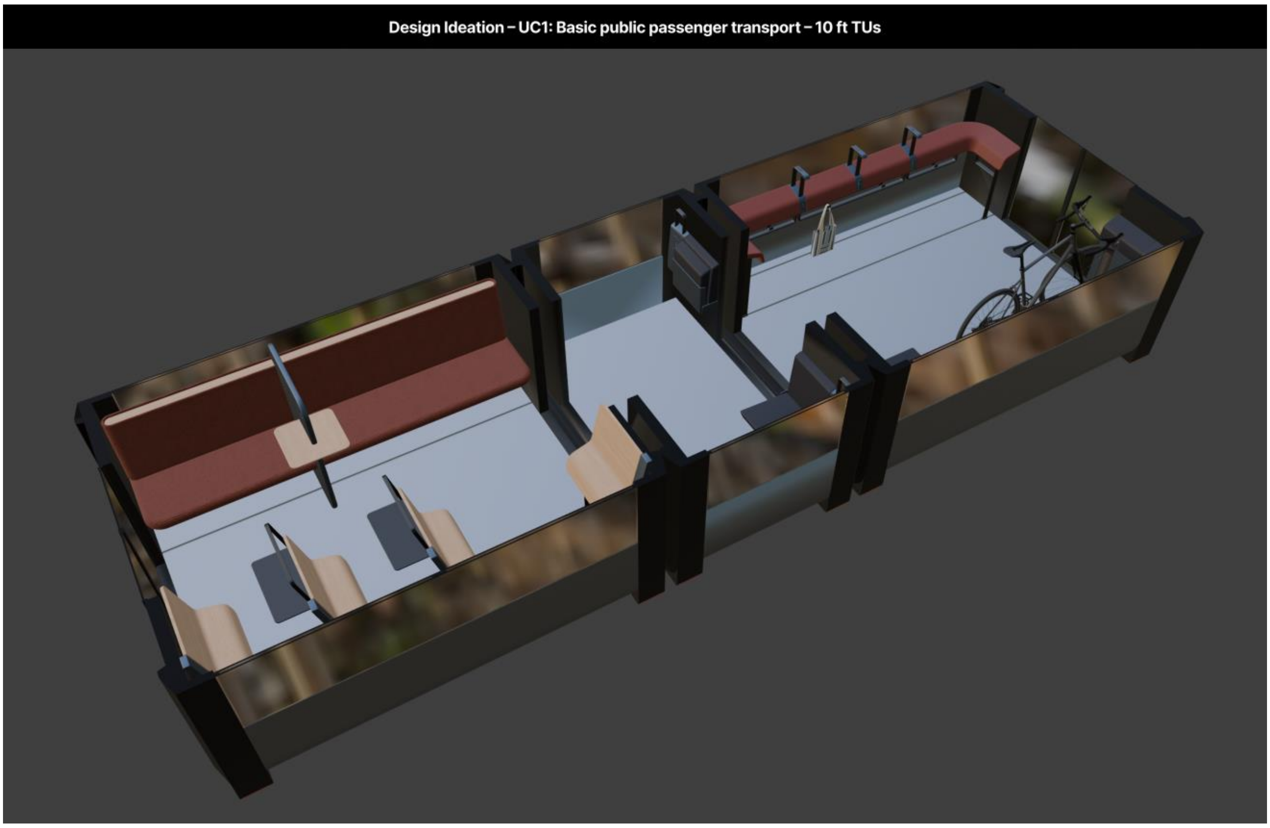


Figure 10: Mixed TU interior layout for UC1 (© moodley)

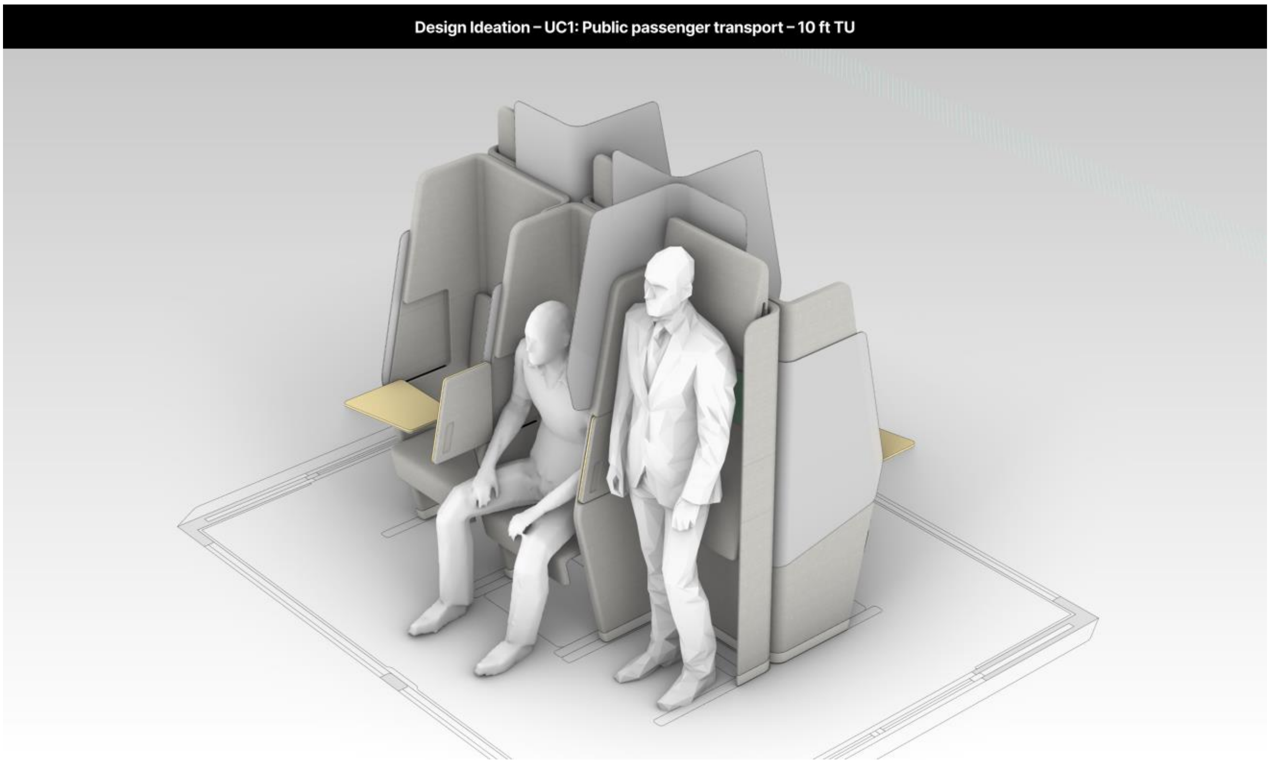


Figure 11: Foldable stand-rest-sit configuration for UC1 (© moodley)

8 Conclusions

The work carried out in WP8 of the Pods4Rail project addressed the challenge of designing flexible and modular Transport Units (TUs) to support diverse operational scenarios, including passenger transport, premium services, PRM accessibility, and container logistics. The core objective was to systematically generate and evaluate TU design variants that meet functional, structural, and regulatory requirements across multiple use cases.

A combined approach of requirement analysis, technological research and morphological analysis was employed. This allowed the identification of relevant design parameters, the organization of possible attribute combinations in a morphological box, and the derivation of coherent morphological paths for each use case. Design variants DEV-A to DEV-E were defined, covering a spectrum of construction strategies, including lightweight metals, thermoplastic composites, bio-based composites, laminated wood and conventional steel carbodies.

Key findings include:

- Modularity enables flexibility: Standardised modules for doors, seats, HVAC and panels allow rapid adaptation across use cases, reducing development time and supporting upgradable or premium configurations.
- Accessibility requirements: PRM compliance requires a minimum 10 ft unit to ensure sufficient wheelchair turning radius and integration of optional sanitary modules.
- Cargo transport solutions: In addition to standardised 10 ft and 20 ft ISO containers, new 5 ft TU units were specifically designed for the Pod system, allowing flexible storage solutions,

efficient handling in small spaces and full integration into the modular Pod framework. Unlike modified half 10 ft ISO containers, these 5 ft units are fully tailored for the system.

- Material trade-offs: Metals and composites offer different balances of weight, durability, and manufacturability; bio-based and wood composites enhance sustainability but need further validation for structural applications.

Evaluation of morphological paths against technical, functional, economic, safety, maintainability, environmental, and social criteria confirmed the suitability of selected variants while highlighting trade-offs, such as cost versus lightweighting or technical feasibility versus social acceptance. The methodology ensures traceability and transparency in design decision-making.

The 5 ft entrance/exit units are essential for the Pod system as they enable side access directly from the platform and optimised use of space within the 10 ft and 20 ft passenger transport units. The new 5 ft cargo units, designed specifically for the system, allow flexible storage solutions. Together, these units provide a modular, scalable and adaptable foundation for sustainable, efficient and user-centred transport solutions, complementing the larger 10 ft and 20 ft passenger units.

The combination of modular construction with plug-and-play modules creates a dynamic, adaptive interior in which functions and equipment can be inserted and exchanged according to demand. Intelligent TU configurations using standardised modules enable rapid adjustments to varying user requirements, operational conditions, or future expansions, enhancing flexibility and efficiency while ensuring sustainable, long-term use of the transport solutions.

Future work should particularly focus on detailed design validation, integration into intermodal transport modes, the exploration of innovative materials and a stronger consideration of subjective comfort requirements to enhance user acceptance.

In conclusion, WP8 has achieved its objectives: a structured and traceable design framework for Transport Units has been established, relevant design variants have been identified, and a modular system has been created that will be carried out in a detailed concept study in WP9.

9 References

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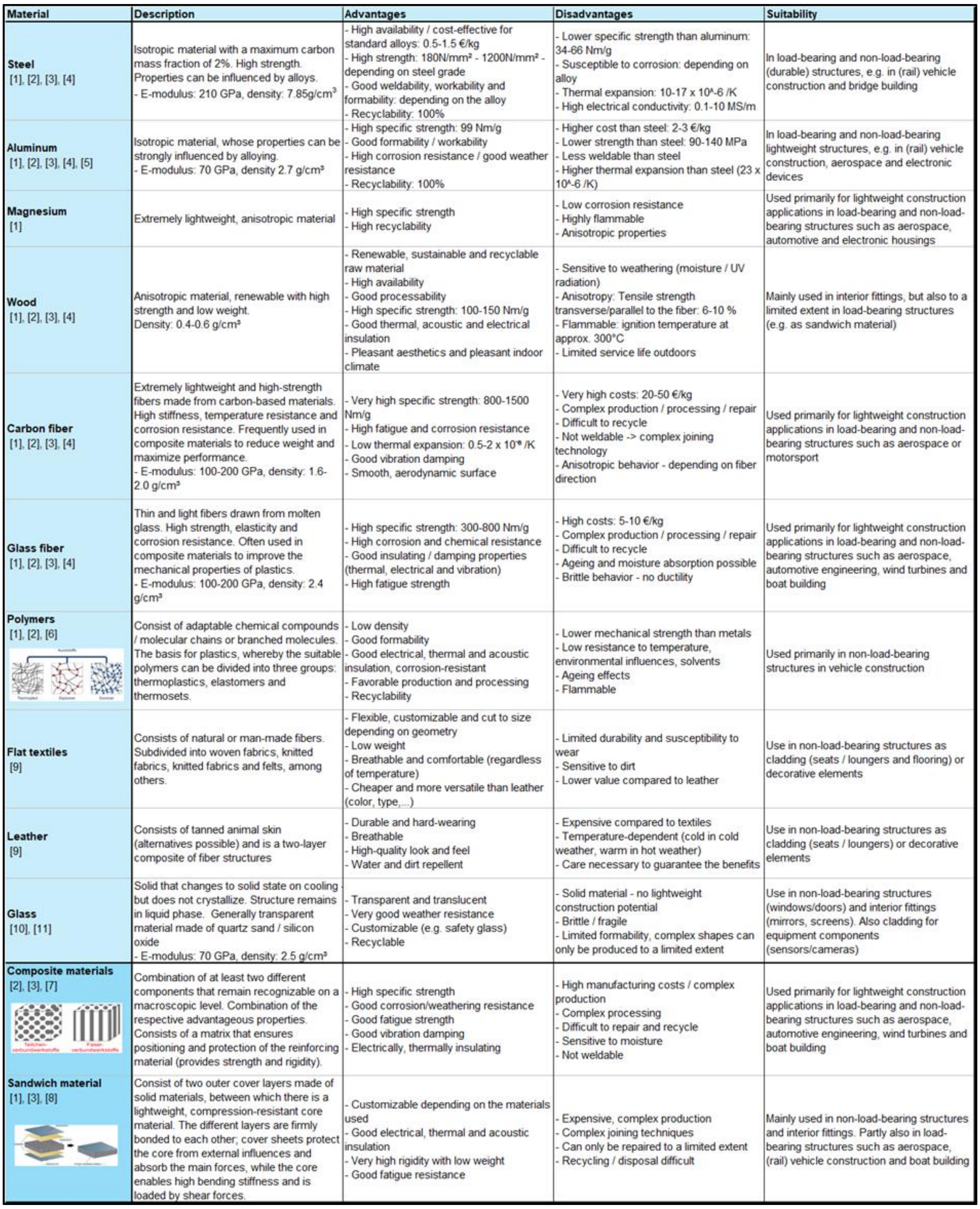
10 Appendices

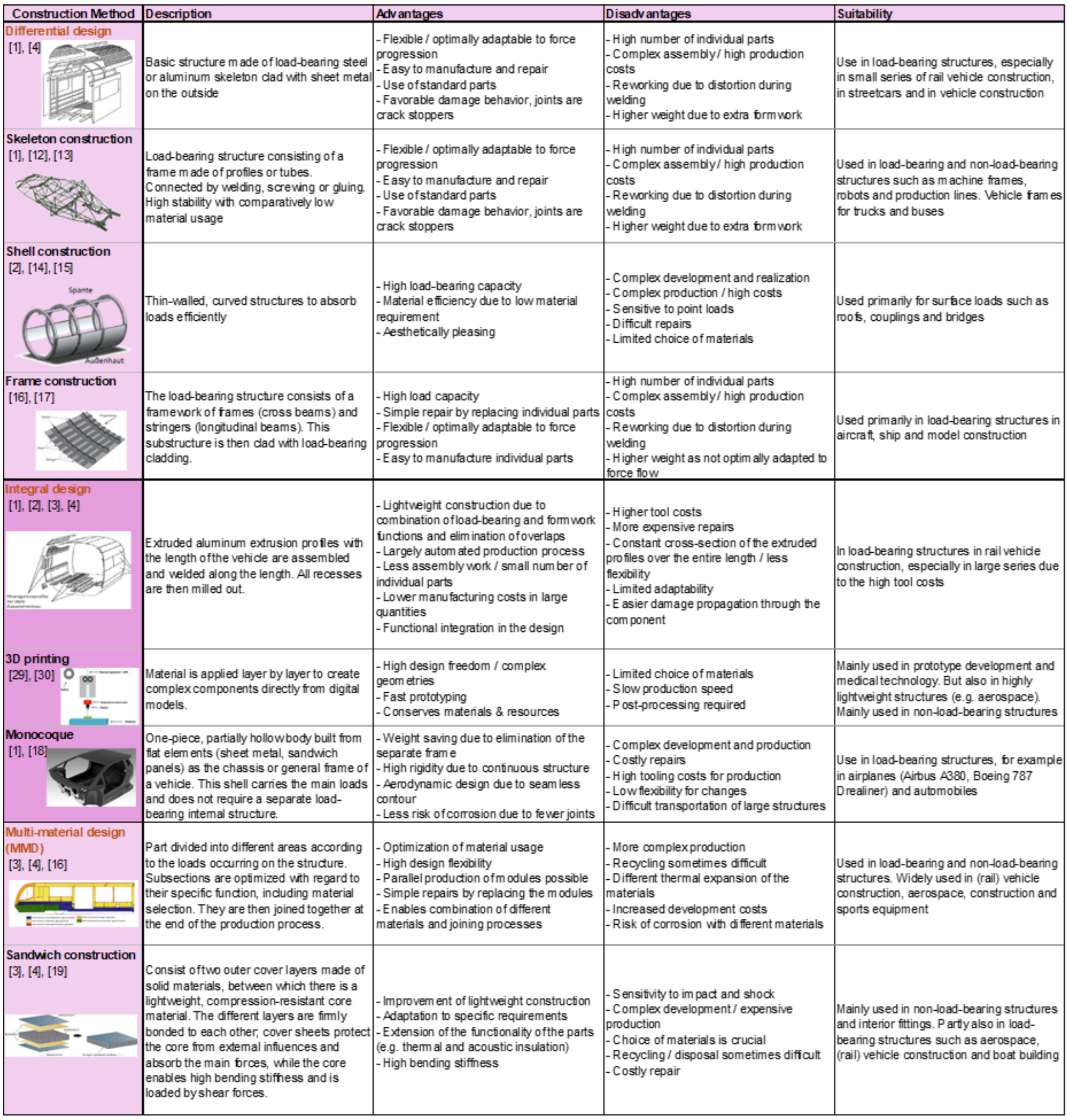
10.1 Appendix A

Table 2: Overview of different materials



Material	Description	Advantages	Disadvantages	Suitability
Steel [1], [2], [3], [4]	Isotropic material with a maximum carbon mass fraction of 2%. High strength. Properties can be influenced by alloys. - E-modulus: 210 GPa, density: 7.85g/cm^3	- High availability / cost-effective for standard alloys: 0.5-1.5 €/kg - High strength: 180N/mm^2 - 1200N/mm^2 - depending on steel grade - Good weldability, workability and formability: depending on the alloy - Recyclability: 100%	- Lower specific strength than aluminum: 34-66 Nm/g - Susceptible to corrosion: depending on alloy - Thermal expansion: 10-17 x 10^-6 /K - High electrical conductivity: 0.1-10 MS/m	In load-bearing and non-load-bearing (durable) structures, e.g. in (rail) vehicle construction and bridge building
Aluminum [1], [2], [3], [4], [5]	Isotropic material, whose properties can be strongly influenced by alloying. - E-modulus: 70 GPa, density 2.7 g/cm^3	- High specific strength: 99 Nm/g - Good formability / workability - High corrosion resistance / good weather resistance - Recyclability: 100%	- Higher cost than steel: 2-3 €/kg - Lower strength than steel: 90-140 MPa - Less weldable than steel - Higher thermal expansion than steel (23 x 10^-6 /K)	In load-bearing and non-load-bearing lightweight structures, e.g. in (rail) vehicle construction, aerospace and electronic devices
Magnesium [1]	Extremely lightweight, anisotropic material	- High specific strength - High recyclability	- Low corrosion resistance - Highly flammable - Anisotropic properties	Used primarily for lightweight construction applications in load-bearing and non-load-bearing structures such as aerospace, automotive and electronic housings
Wood [1], [2], [3], [4]	Anisotropic material, renewable with high strength and low weight. Density: 0.4-0.6 g/cm^3	- Renewable, sustainable and recyclable raw material - High availability - Good processability - High specific strength: 100-150 Nm/g - Good thermal, acoustic and electrical insulation - Pleasant aesthetics and pleasant indoor climate	- Sensitive to weathering (moisture / UV radiation) - Anisotropy: Tensile strength transverse/parallel to the fiber: 6-10 % - Flammable: ignition temperature at approx. 300°C - Limited service life outdoors	Mainly used in interior fittings, but also to a limited extent in load-bearing structures (e.g. as sandwich material)
Carbon fiber [1], [2], [3], [4]	Extremely lightweight and high-strength fibers made from carbon-based materials. High stiffness, temperature resistance and corrosion resistance. Frequently used in composite materials to reduce weight and maximize performance. - E-modulus: 100-200 GPa, density: 1.6-2.0 g/cm^3	- Very high specific strength: 800-1500 Nm/g - High fatigue and corrosion resistance - Low thermal expansion: 0.5-2 x 10^{-6} /K - Good vibration damping - Smooth, aerodynamic surface	- Very high costs: 20-50 €/kg - Complex production / processing / repair - Difficult to recycle - Not weldable -> complex joining technology - Anisotropic behavior - depending on fiber direction	Used primarily for lightweight construction applications in load-bearing and non-load-bearing structures such as aerospace or motorsport
Glass fiber [1], [2], [3], [4]	Thin and light fibers drawn from molten glass. High strength, elasticity and corrosion resistance. Often used in composite materials to improve the mechanical properties of plastics. - E-modulus: 100-200 GPa, density: 2.4 g/cm^3	- High specific strength: 300-800 Nm/g - High corrosion and chemical resistance - Good insulating / damping properties (thermal, electrical and vibration) - High fatigue strength	- High costs: 5-10 €/kg - Complex production / processing / repair - Difficult to recycle - Ageing and moisture absorption possible - Brittle behavior - no ductility	Used primarily for lightweight construction applications in load-bearing and non-load-bearing structures such as aerospace, automotive engineering, wind turbines and boat building
Polymers [1], [2], [6]	Consist of adaptable chemical compounds / molecular chains or branched molecules. The basis for plastics, whereby the suitable polymers can be divided into three groups: thermoplastics, elastomers and thermosets.	- Low density - Good formability - Good electrical, thermal and acoustic insulation, corrosion-resistant - Favorable production and processing - Recyclability	- Lower mechanical strength than metals - Low resistance to temperature, environmental influences, solvents - Ageing effects - Flammable	Used primarily in non-load-bearing structures in vehicle construction
Flat textiles [9]	Consists of natural or man-made fibers. Subdivided into woven fabrics, knitted fabrics, knitted fabrics and felts, among others.	- Flexible, customizable and cut to size depending on geometry - Low weight - Breathable and comfortable (regardless of temperature) - Cheaper and more versatile than leather (color, type,...)	- Limited durability and susceptibility to wear - Sensitive to dirt - Lower value compared to leather	Use in non-load-bearing structures as cladding (seats / loungers and flooring) or decorative elements
Leather [9]	Consists of tanned animal skin (alternatives possible) and is a two-layer composite of fiber structures	- Durable and hard-wearing - Breathable - High-quality look and feel - Water and dirt repellent	- Expensive compared to textiles - Temperature-dependent (cold in cold weather, warm in hot weather) - Care necessary to guarantee the benefits	Use in non-load-bearing structures as cladding (seats / loungers) or decorative elements
Glass [10], [11]	Solid that changes to solid state on cooling but does not crystallize. Structure remains in liquid phase. Generally transparent material made of quartz sand / silicon oxide - E-modulus: 70 GPa, density: 2.5 g/cm^3	- Transparent and translucent - Very good weather resistance - Customizable (e.g. safety glass) - Recyclable	- Solid material - no lightweight construction potential - Brittle / fragile - Limited formability, complex shapes can only be produced to a limited extent	Use in non-load-bearing structures (windows/doors) and interior fittings (mirrors, screens). Also cladding for equipment components (sensors/cameras)
Composite materials [2], [3], [7]	Combination of at least two different components that remain recognizable on a macroscopic level. Combination of the respective advantageous properties. Consists of a matrix that ensures positioning and protection of the reinforcing material (provides strength and rigidity).	- High specific strength - Good corrosion/weathering resistance - Good fatigue strength - Good vibration damping - Electrically, thermally insulating	- High manufacturing costs / complex production - Complex processing - Difficult to repair and recycle - Sensitive to moisture - Not weldable	Used primarily for lightweight construction applications in load-bearing and non-load-bearing structures such as aerospace, automotive engineering, wind turbines and boat building
Sandwich material [1], [3], [8]	Consist of two outer cover layers made of solid materials, between which there is a lightweight, compression-resistant core material. The different layers are firmly bonded to each other; cover sheets protect the core from external influences and absorb the main forces, while the core enables high bending stiffness and is loaded by shear forces.	- Customizable depending on the materials used - Good electrical, thermal and acoustic insulation - Very high rigidity with low weight - Good fatigue resistance	- Expensive, complex production - Complex joining techniques - Can only be repaired to a limited extent - Recycling / disposal difficult	Mainly used in non-load-bearing structures and interior fittings. Partly also in load-bearing structures such as aerospace, (rail) vehicle construction and boat building

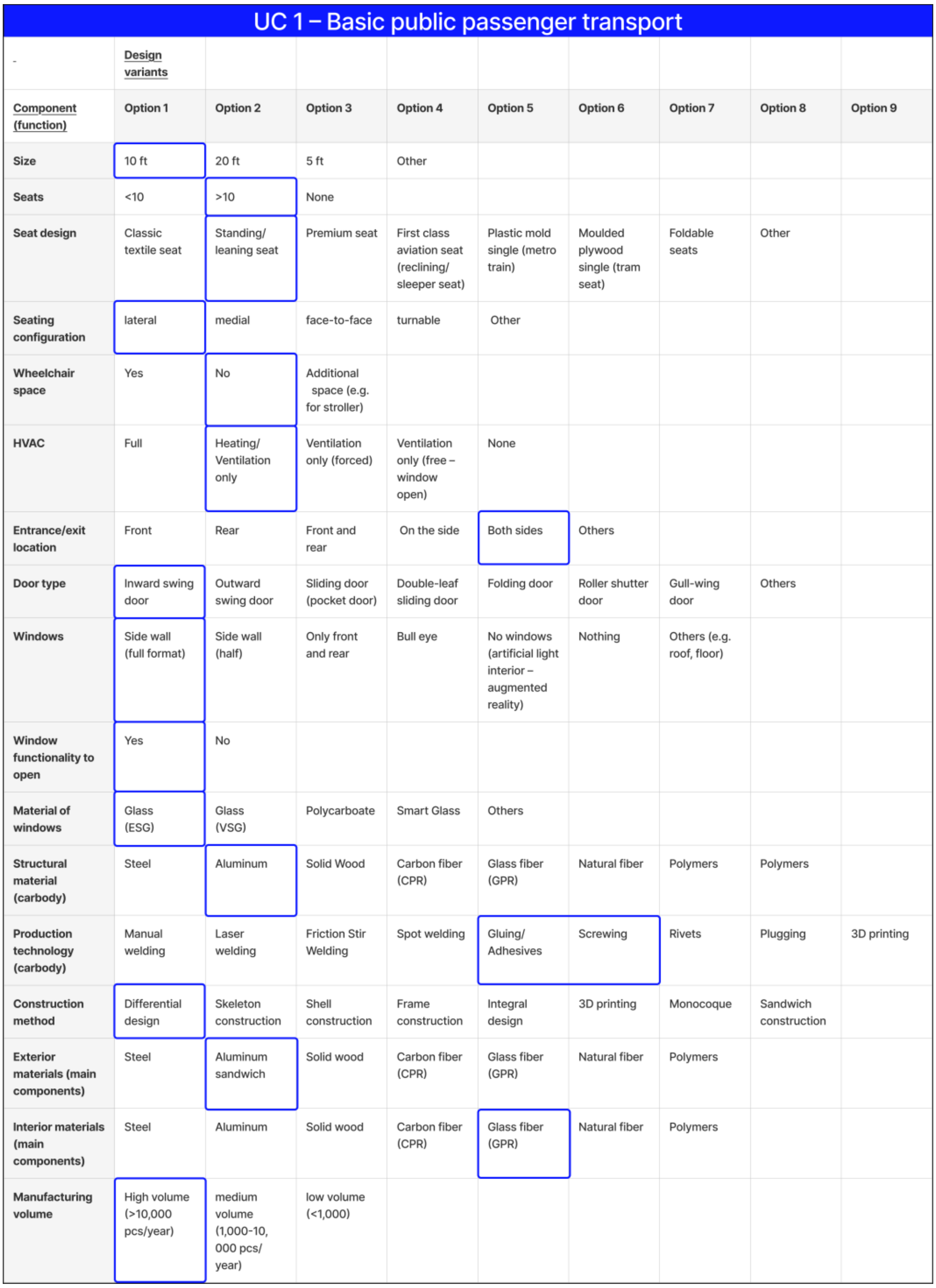
Table 3: Overview of different design methods



Construction Method	Description	Advantages	Disadvantages	Suitability
Differential design [1], [4]	Basic structure made of load-bearing steel or aluminum skeleton clad with sheet metal on the outside	- Flexible / optimally adaptable to force progression - Easy to manufacture and repair - Use of standard parts - Favorable damage behavior, joints are crack stoppers	- High number of individual parts - Complex assembly / high production costs - Reworking due to distortion during welding - Higher weight due to extra formwork	Use in load-bearing structures, especially in small series of rail vehicle construction, in streetcars and in vehicle construction
Skeleton construction [1], [12], [13]	Load-bearing structure consisting of a frame made of profiles or tubes. Connected by welding, screwing or gluing. High stability with comparatively low material usage	- Flexible / optimally adaptable to force progression - Easy to manufacture and repair - Use of standard parts - Favorable damage behavior, joints are crack stoppers	- High number of individual parts - Complex assembly / high production costs - Reworking due to distortion during welding - Higher weight due to extra formwork	Used in load-bearing and non-load-bearing structures such as machine frames, robots and production lines. Vehicle frames for trucks and buses
Shell construction [2], [14], [15]	Thin-walled, curved structures to absorb loads efficiently	- High load-bearing capacity - Material efficiency due to low material requirement - Aesthetically pleasing	- Complex development and realization - Complex production / high costs - Sensitive to point loads - Difficult repairs - Limited choice of materials	Used primarily for surface loads such as roofs, couplings and bridges
Frame construction [16], [17]	The load-bearing structure consists of a framework of frames (cross beams) and stringers (longitudinal beams). This substructure is then clad with load-bearing cladding.	- High load capacity - Simple repair by replacing individual parts - Flexible / optimally adaptable to force progression - Easy to manufacture individual parts	- High number of individual parts - Complex assembly / high production costs - Reworking due to distortion during welding - Higher weight as not optimally adapted to force flow	Used primarily in load-bearing structures in aircraft, ship and model construction
Integral design [1], [2], [3], [4]	Extruded aluminum extrusion profiles with the length of the vehicle are assembled and welded along the length. All recesses are then milled out.	- Lightweight construction due to combination of load-bearing and formwork functions and elimination of overlaps - Largely automated production process - Less assembly work / small number of individual parts - Lower manufacturing costs in large quantities - Functional integration in the design	- Higher tool costs - More expensive repairs - Constant cross-section of the extruded profiles over the entire length / less flexibility - Limited adaptability - Easier damage propagation through the component	In load-bearing structures in rail vehicle construction, especially in large series due to the high tool costs
3D printing [29], [30]	Material is applied layer by layer to create complex components directly from digital models.	- High design freedom / complex geometries - Fast prototyping - Conserves materials & resources	- Limited choice of materials - Slow production speed - Post-processing required	Mainly used in prototype development and medical technology. But also in highly lightweight structures (e.g. aerospace). Mainly used in non-load-bearing structures
Monocoque [1], [18]	One-piece, partially hollow body built from flat elements (sheet metal, sandwich panels) as the chassis or general frame of a vehicle. This shell carries the main loads and does not require a separate load-bearing internal structure.	- Weight saving due to elimination of the separate frame - High rigidity due to continuous structure - Aerodynamic design due to seamless contour - Less risk of corrosion due to fewer joints	- Complex development and production - Costly repairs - High tooling costs for production - Low flexibility for changes - Difficult transportation of large structures	Use in load-bearing structures, for example in airplanes (Airbus A380, Boeing 787 Drealiner) and automobiles
Multi-material design (MMD) [3], [4], [16]	Part divided into different areas according to the loads occurring on the structure. Subsections are optimized with regard to their specific function, including material selection. They are then joined together at the end of the production process.	- Optimization of material usage - High design flexibility - Parallel production of modules possible - Simple repairs by replacing the modules - Enables combination of different materials and joining processes	- More complex production - Recycling sometimes difficult - Different thermal expansion of the materials - Increased development costs - Risk of corrosion with different materials	Used in load-bearing and non-load-bearing structures. Widely used in (rail) vehicle construction, aerospace, construction and sports equipment
Sandwich construction [3], [4], [19]	Consist of two outer cover layers made of solid materials, between which there is a lightweight, compression-resistant core material. The different layers are firmly bonded to each other, cover sheets protect the core from external influences and absorb the main forces, while the core enables high bending stiffness and is loaded by shear forces.	- Improvement of lightweight construction - Adaptation to specific requirements - Extension of the functionality of the parts (e.g. thermal and acoustic insulation) - High bending stiffness	- Sensitivity to impact and shock - Complex development / expensive production - Choice of materials is crucial - Recycling / disposal sometimes difficult - Costly repair	Mainly used in non-load-bearing structures and interior fittings. Partly also in load-bearing structures such as aerospace, (rail) vehicle construction and boat building

10.2 Appendix B

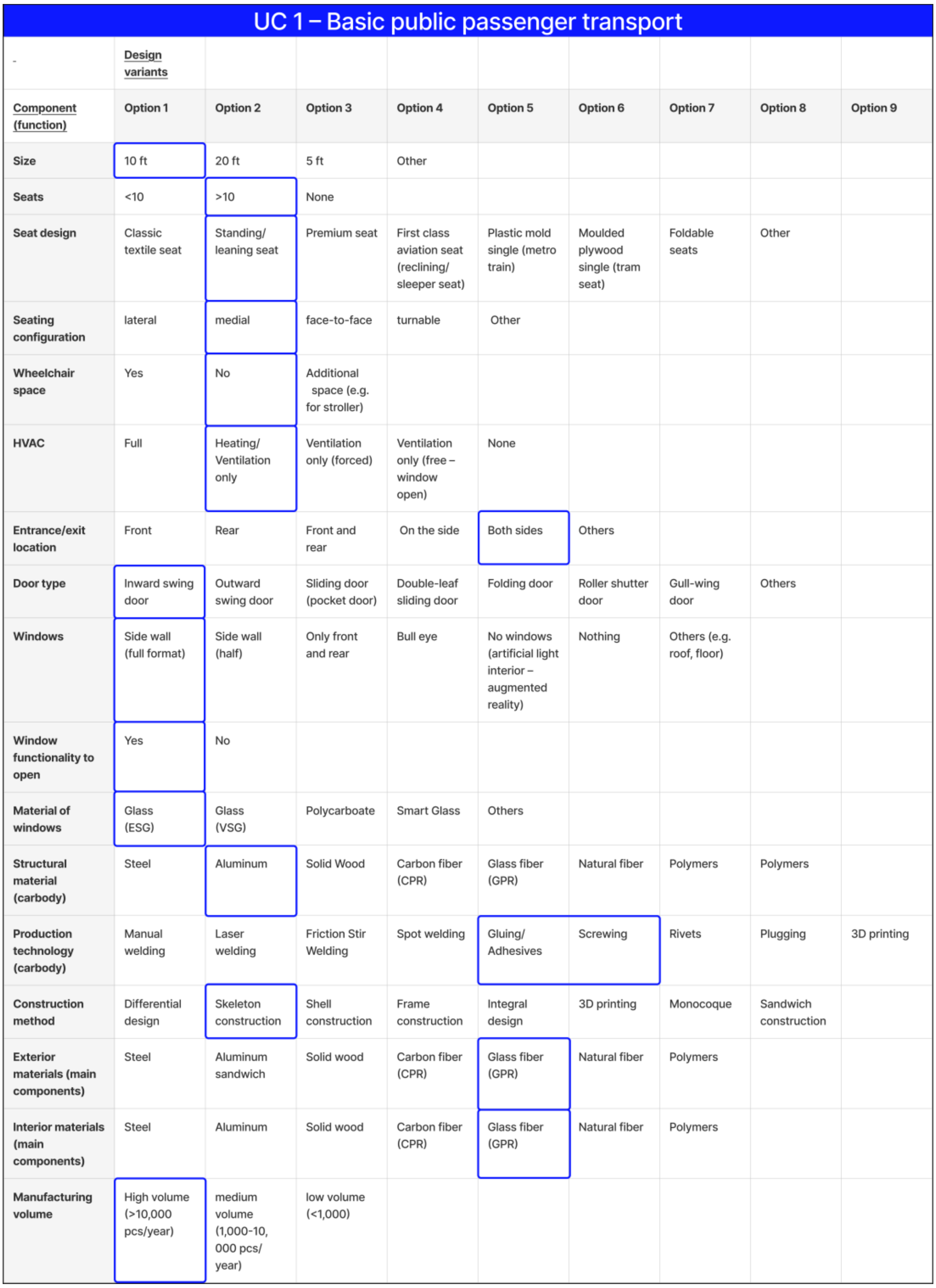
Table 4: Morphological box for UC1: Basic public passenger transport – critical path DEV-A



UC 1 – Basic public passenger transport

-	Design variants								
Component (function)	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Size	[✓ 10 ft]	20 ft	5 ft	Other					
Seats	<10	[✓ >10]	None						
Seat design	Classic textile seat	[✓ Standing/ leaning seat]	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	Foldable seats	Other	
Seating configuration	[✓ lateral]	medial	face-to-face	turnable	Other				
Wheelchair space	Yes	[✓ No]	Additional space (e.g. for stroller)						
HVAC	Full	[✓ Heating/ Ventilation only]	Ventilation only (forced)	Ventilation only (free – window open)	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	[✓ Both sides]	Others			
Door type	[✓ Inward swing door]	Outward swing door	Sliding door (pocket door)	Double-leaf sliding door	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	[✓ Side wall (full format)]	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	[✓ Yes]	No							
Material of windows	[✓ Glass (ESG)]	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	Steel	[✓ Aluminum]	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	Laser welding	Friction Stir Welding	Spot welding	[✓ Gluing/ Adhesives]	[✓ Screwing]	Rivets	Plugging	3D printing
Construction method	[✓ Differential design]	Skeleton construction	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	[✓ Aluminum sandwich]	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Interior materials (main components)	Steel	Aluminum	Solid wood	Carbon fiber (CPR)	[✓ Glass fiber (GPR)]	Natural fiber	Polymers		
Manufacturing volume	[✓ High volume (>10,000 pcs/year)]	medium volume (1,000-10, 000 pcs/ year)	low volume (<1,000)						

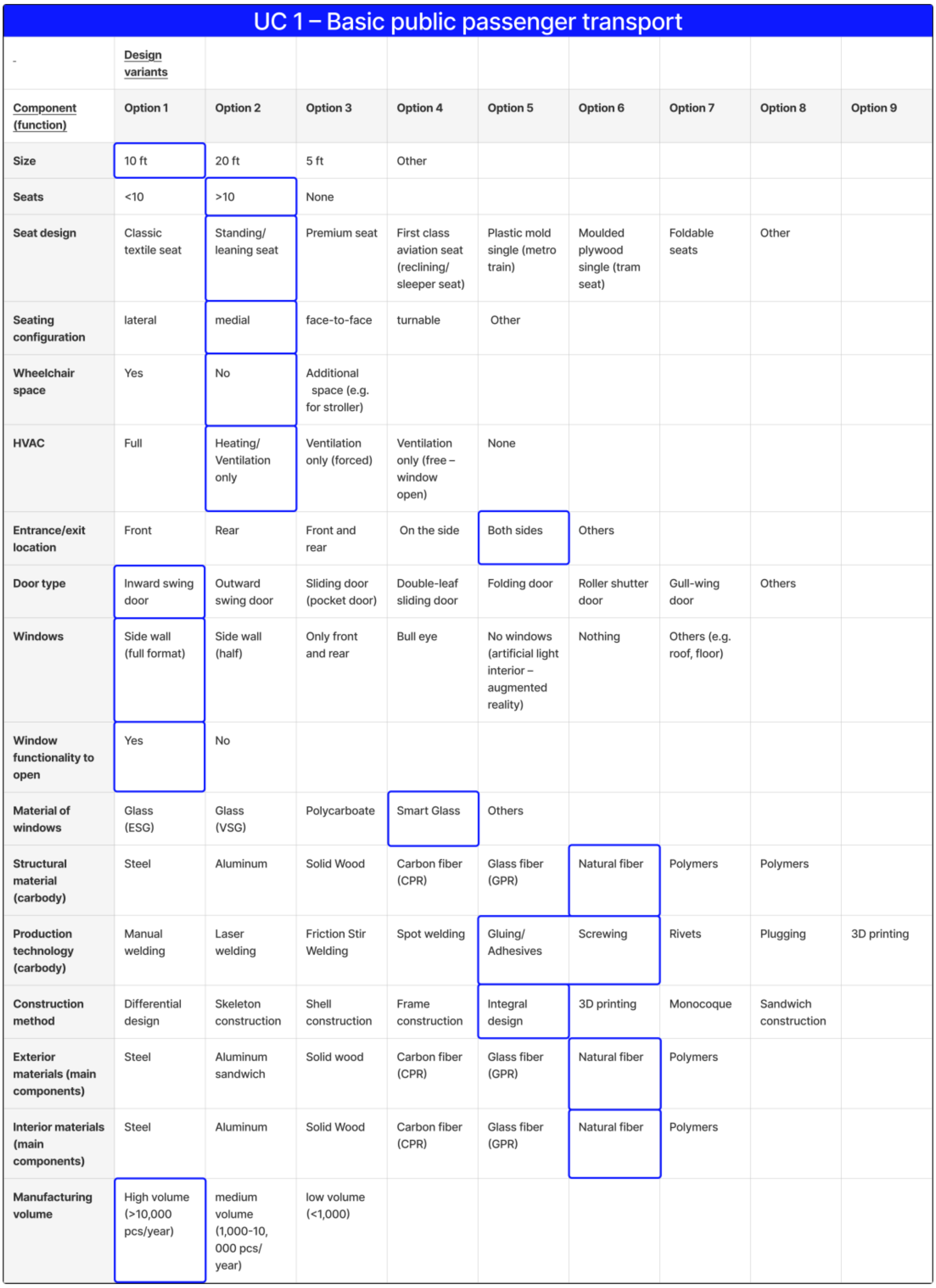
Table 5: Morphological box for UC1: Basic public passenger transport – critical path DEV-B



UC 1 – Basic public passenger transport

-	Design variants								
Component (function)	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Size	[✓ 10 ft]	20 ft	5 ft	Other					
Seats	<10	[✓ >10]	None						
Seat design	Classic textile seat	[✓ Standing/ leaning seat]	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	Foldable seats	Other	
Seating configuration	lateral	[✓ medial]	face-to-face	turnable	Other				
Wheelchair space	Yes	[✓ No]	Additional space (e.g. for stroller)						
HVAC	Full	[✓ Heating/ Ventilation only]	Ventilation only (forced)	Ventilation only (free – window open)	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	[✓ Both sides]	Others			
Door type	[✓ Inward swing door]	Outward swing door	Sliding door (pocket door)	Double-leaf sliding door	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	[✓ Side wall (full format)]	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	[✓ Yes]	No							
Material of windows	[✓ Glass (ESG)]	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	Steel	[✓ Aluminum]	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	Laser welding	Friction Stir Welding	Spot welding	[✓ Gluing/ Adhesives]	[✓ Screwing]	Rivets	Plugging	3D printing
Construction method	Differential design	[✓ Skeleton construction]	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	Aluminum sandwich	Solid wood	Carbon fiber (CPR)	[✓ Glass fiber (GPR)]	Natural fiber	Polymers		
Interior materials (main components)	Steel	Aluminum	Solid wood	Carbon fiber (CPR)	[✓ Glass fiber (GPR)]	Natural fiber	Polymers		
Manufacturing volume	[✓ High volume (>10,000 pcs/year)]	medium volume (1,000-10, 000 pcs/ year)	low volume (<1,000)						

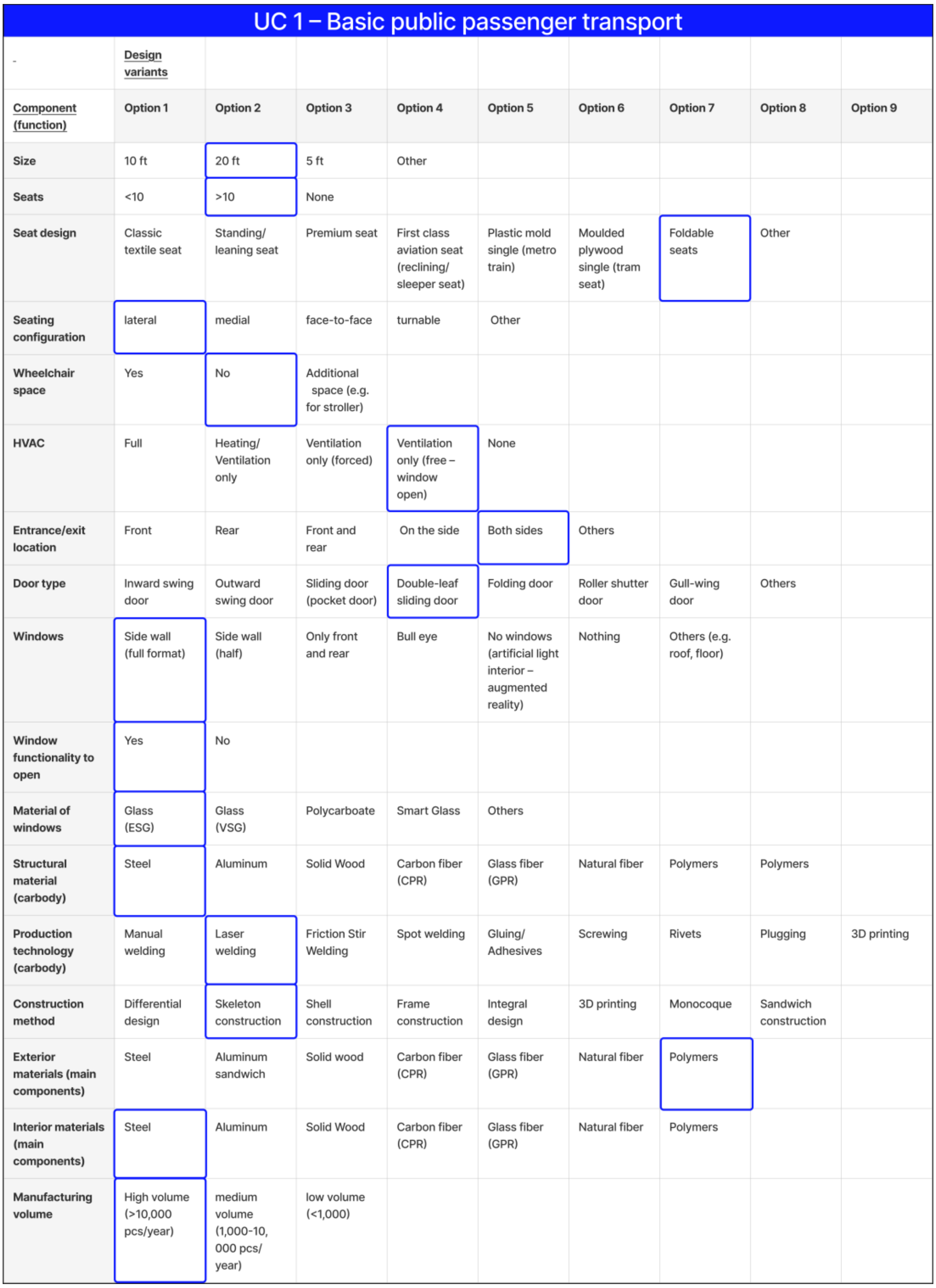
Table 6: Morphological box for UC1: Basic public passenger transport – critical path DEV-C



UC 1 – Basic public passenger transport

-	**Design variants**								
Component (function)	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Size	10 ft	20 ft	5 ft	Other					
Seats	<10	>10	None						
Seat design	Classic textile seat	Standing/ leaning seat	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	Foldable seats	Other	
Seating configuration	lateral	medial	face-to-face	turnable	Other				
Wheelchair space	Yes	No	Additional space (e.g. for stroller)						
HVAC	Full	Heating/ Ventilation only	Ventilation only (forced)	Ventilation only (free – window open)	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	Both sides	Others			
Door type	Inward swing door	Outward swing door	Sliding door (pocket door)	Double-leaf sliding door	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	Side wall (full format)	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	Yes	No							
Material of windows	Glass (ESG)	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	Steel	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	Laser welding	Friction Stir Welding	Spot welding	Gluing/ Adhesives	Screwing	Rivets	Plugging	3D printing
Construction method	Differential design	Skeleton construction	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	Aluminum sandwich	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Interior materials (main components)	Steel	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Manufacturing volume	High volume (>10,000 pcs/year)	medium volume (1,000-10, 000 pcs/ year)	low volume (<1,000)						

Table 7: Morphological box for UC1: Basic public passenger transport – critical path DEV-D



UC 1 – Basic public passenger transport

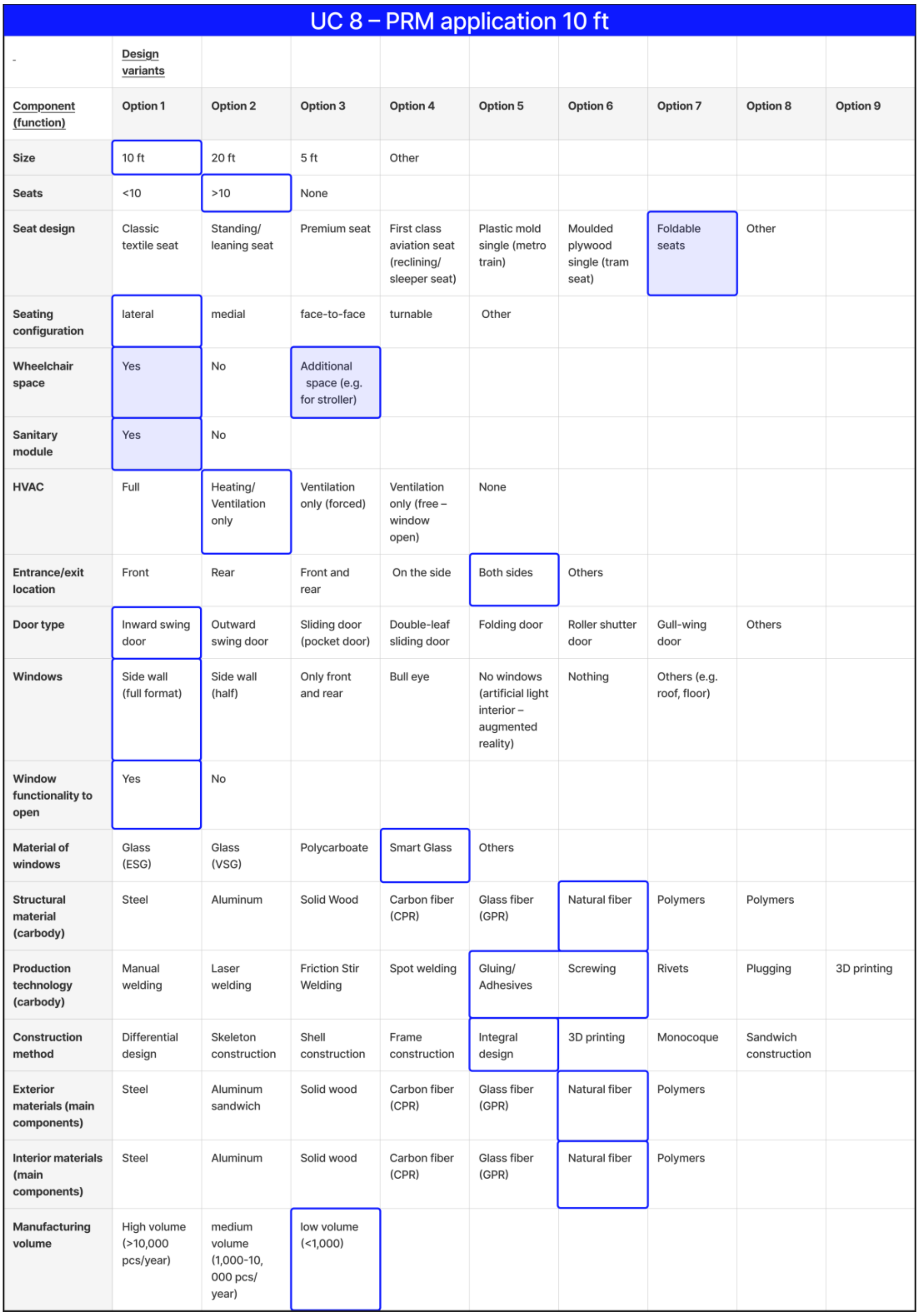
-	**Design variants**								
Component (function)	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Size	10 ft	[✓ 20 ft]	5 ft	Other					
Seats	<10	[✓ >10]	None						
Seat design	Classic textile seat	Standing/ leaning seat	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	[✓ Foldable seats]	Other	
Seating configuration	[✓ lateral]	medial	face-to-face	turnable	Other				
Wheelchair space	Yes	[✓ No]	Additional space (e.g. for stroller)						
HVAC	Full	Heating/ Ventilation only	Ventilation only (forced)	[✓ Ventilation only (free – window open)]	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	[✓ Both sides]	Others			
Door type	Inward swing door	Outward swing door	Sliding door (pocket door)	[✓ Double-leaf sliding door]	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	[✓ Side wall (full format)]	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	[✓ Yes]	No							
Material of windows	[✓ Glass (ESG)]	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	[✓ Steel]	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	[✓ Laser welding]	Friction Stir Welding	Spot welding	Gluing/ Adhesives	Screwing	Rivets	Plugging	3D printing
Construction method	Differential design	[✓ Skeleton construction]	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	Aluminum sandwich	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	[✓ Polymers]		
Interior materials (main components)	[✓ Steel]	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Manufacturing volume	[✓ High volume (>10,000 pcs/year)]	medium volume (1,000-10,000 pcs/ year)	low volume (<1,000)						

Table 8: Morphological box for UC2: Premium public passenger transport – critical path DEV-C

UC 2 – Premium public passenger transport

-	Design variants								
Component (function)	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Size	10 ft	20 ft	5 ft	Other					
Seats	<10	>10	None						
Seat design	Classic textile seat	Standing/ leaning seat	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	Foldable seats	Other	
Seating configuration	lateral	medial	face-to-face	turnable	Other				
Wheelchair space	Yes	No	Additional space (e.g. for stroller)						
HVAC	Full	Heating/ Ventilation only	Ventilation only (forced)	Ventilation only (free – window open)	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	Both sides	Others			
Door type	Inward swing door	Outward swing door	Sliding door (pocket door)	Double-leaf sliding door	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	Side wall (full format)	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	Yes	No							
Material of windows	Glass (ESG)	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	Steel	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	Laser welding	Friction Stir Welding	Spot welding	Gluing/ Adhesives	Screwing	Rivets	Plugging	3D printing
Construction method	Differential design	Skeleton construction	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	Aluminum sandwich	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Interior materials (main components)	Steel	Aluminum	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Manufacturing volume	High volume (>10,000 pcs/year)	medium volume (1,000-10,000 pcs/ year)	low volume (<1,000)						

Table 9: Morphological box for UC8: PRM application (10 ft) – critical path DEV-C



UC 8 – PRM application 10 ft

-	Design variants								
Component (function)	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
Size	10 ft	20 ft	5 ft	Other					
Seats	<10	>10	None						
Seat design	Classic textile seat	Standing/ leaning seat	Premium seat	First class aviation seat (reclining/ sleeper seat)	Plastic mold single (metro train)	Moulded plywood single (tram seat)	Foldable seats	Other	
Seating configuration	lateral	medial	face-to-face	turnable	Other				
Wheelchair space	Yes	No	Additional space (e.g. for stroller)						
Sanitary module	Yes	No							
HVAC	Full	Heating/ Ventilation only	Ventilation only (forced)	Ventilation only (free – window open)	None				
Entrance/exit location	Front	Rear	Front and rear	On the side	Both sides	Others			
Door type	Inward swing door	Outward swing door	Sliding door (pocket door)	Double-leaf sliding door	Folding door	Roller shutter door	Gull-wing door	Others	
Windows	Side wall (full format)	Side wall (half)	Only front and rear	Bull eye	No windows (artificial light interior – augmented reality)	Nothing	Others (e.g. roof, floor)		
Window functionality to open	Yes	No							
Material of windows	Glass (ESG)	Glass (VSG)	Polycarboate	Smart Glass	Others				
Structural material (carbody)	Steel	Aluminum	Solid Wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers	Polymers	
Production technology (carbody)	Manual welding	Laser welding	Friction Stir Welding	Spot welding	Gluing/ Adhesives	Screwing	Rivets	Plugging	3D printing
Construction method	Differential design	Skeleton construction	Shell construction	Frame construction	Integral design	3D printing	Monocoque	Sandwich construction	
Exterior materials (main components)	Steel	Aluminum sandwich	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Interior materials (main components)	Steel	Aluminum	Solid wood	Carbon fiber (CPR)	Glass fiber (GPR)	Natural fiber	Polymers		
Manufacturing volume	High volume (>10,000 pcs/year)	medium volume (1,000-10,000 pcs/ year)	low volume (<1,000)						