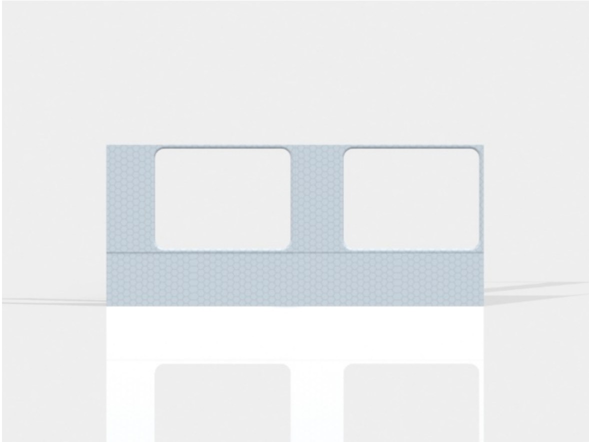

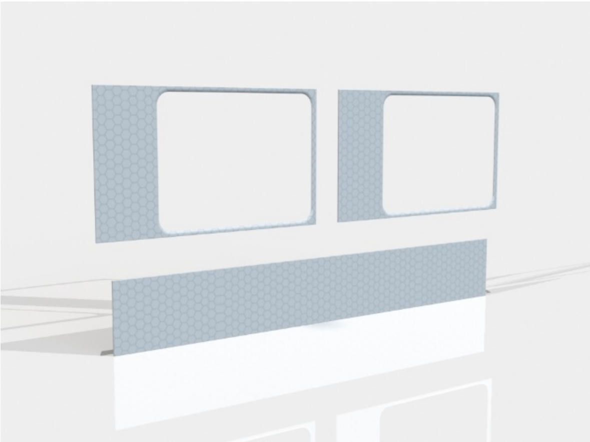

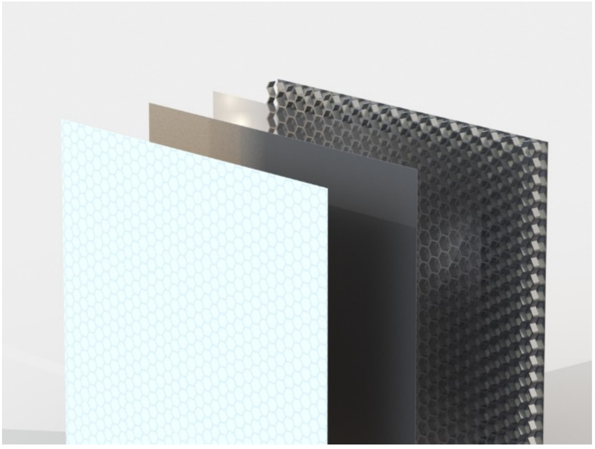

CONCECPT REPORT

SUSTAINABLE INTERIOR SIDE WALL

ONWARDS TO FULLY CIRCULAR TRAINS

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INDEX

1 INTRODUCTION

NS is a frontrunner on fcircularity in the mobility sector and wants to keep this position. The goal is to have fully circular trains in 2030, and although trains are already largely circular, there are still a couple of train parts that do not have a circular configuration yet. These non-circular train parts and their materials cannot be reused, reshaped, repurposed or recycled in a feasible manner on a large scale, so instead they are incinerated or moved to landfill. One of these parts is the sidewall panel in the train interior. This report explores the development of a circular alternative to the sidewall panel, which combines the desired material properties with a circular construction.

1.1 CURRENT SIDE WALL PANEL

This paragraph will describe the current configuration of the side wall panels, as well as their issues regarding circularity. This will illustrate why a circular alternative is needed and what changes need to be made in order to achieve a more circular construction.

1.1.1 Design for single use

The current side wall panels are designed specifically for NS, and tailored for the specific train type. The side wall panels since VIRM-1 in 1994 are made from a composite material of thermoset polyester resin with glass fibre reinforcement. Composite material is created by embedding the reinforcement fibres into the resin matrix (Royal Society of Chemistry, 2015). Glass fibre composite is a lightweight yet sturdy material, and it becomes fire retardant with the right additives. This makes it an ideal material for use in the train, and creates a long product life for the panels.

The usage scenario for the current side wall panel is shown in Figure 1. It shows how the wall panel moves through its lifecycle from begin to end of life, which takes around 15-20 years.

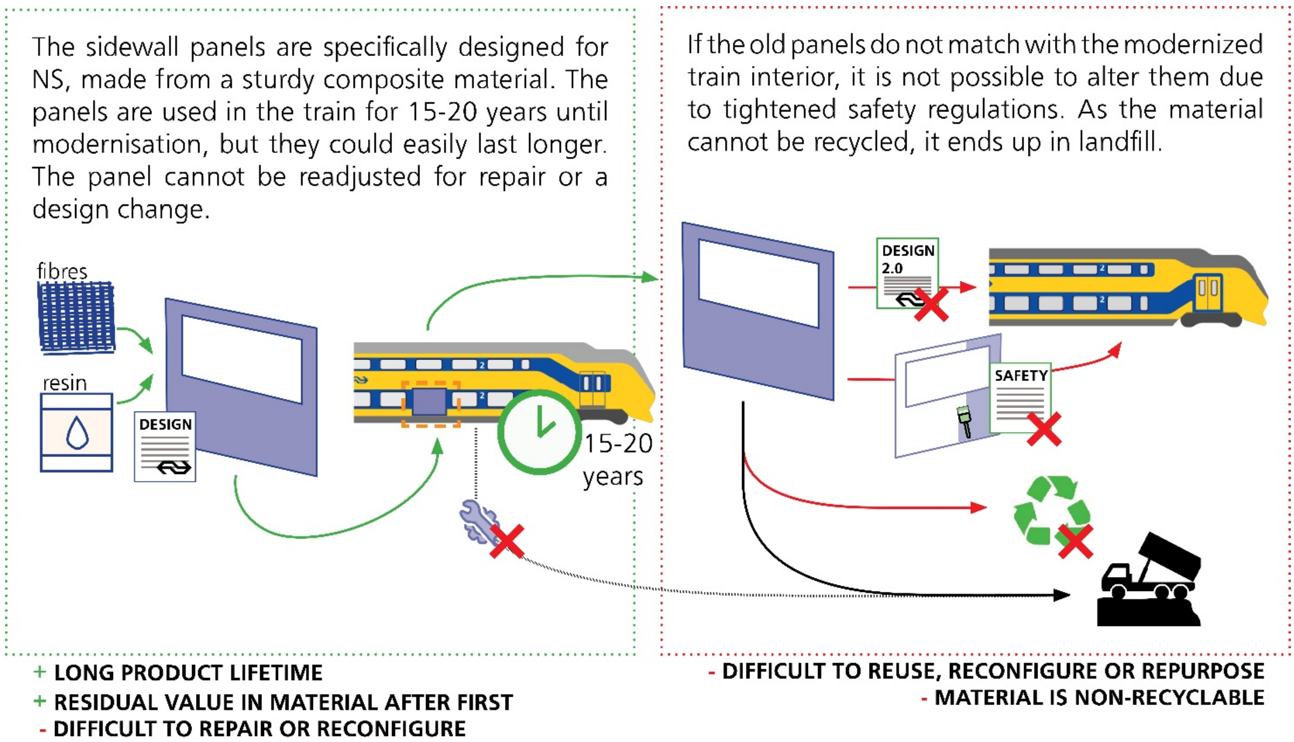


Figure 1: Usage scenario of the current side wall panel

After this first use cycle, the material has enough residual value to consider a second use cycle. This could be reuse in the train or repurpose outside the train. This second use cycle, however, is difficult to realize. At the modernisation the train interior is renewed, and the old panels might not match with this new design. For example, at the VIRM-1 modernisation, the panels could not be reused as they had the wrong colour. Reconfiguring the panels means that they need to comply with the new safety regulations, such as fire safety. These regulations have tightened in the 15-20 years since the panels have been designed, which makes it very likely that the old panels will not be approved. Repurposing the panels outside the train is also challenging, as the panels have a very specific shape and reshaping the thermoset material is not feasible.

| 1.1.2 Design for disposal

As the panel cannot be reused or repurposed in any way, it will reach its end-of-life at the modernisation. At the moment, the composite panels are trashed and moved to landfill. Considering the Ladder van Lansink, recycling should be the only option here, but this is difficult for composite materials as the fibres are deeply embedded into the resin. It is not yet feasible to recycle the material or its resources on a large scale in such a way that it can be reused in the same application. Especially for glass fibre composites, the glass fibres are damaged too much in the process, and virgin glass fibre is far too cheap for the low-grade recycled fibres to be able to compete. Often when "recycling" composite, the material is burnt or shredded, and the residue is used as filler in other materials. This means a lot of the material value is lost, which means it not a circular option (Van Oudheusden, 2019). Of course, recycling processes can still develop over time, but composite materials have already been around for a long time. Therefore, waiting for this change to happen does not fit the frontrunner position that NS wants to take in the circular economy. A (recyclable) circular alternative is needed instead.

1.2 PROPOSED ALTERNATIVE: HONEYCOMB PANELS

One possibility to construct a circular side wall panel is to use a sandwich material with a honeycomb core. This material is, similarly to composite material, lightweight yet strong. However, honeycomb core panels can be constructed from mono-materials, which makes it much easier to recycle.

| 1.2.1 Honeycomb construction

Honeycomb panels are created by sandwiching a honeycomb core between two plates or skins, as shown in Figure 2. The geometry of the core varies, but they all possess a layer of hollow cells (mostly hexagonal) between thin vertical walls. This construction allows for lightweight honeycomb structures with substantial structural strength (GlobalSpec, 2020). Other benefits for honeycomb panels are continued performance after failure, efficient sound and energy absorption, and for plastic honeycombs also good chemical and moisture resistance (Plascore, Inc., 2018). As the used materials do not mix but remain separate layers, it could be a more sustainable alternative to fibre-matrix composites, if the panel is constructed in a reversible manner. The next chapter will elaborate on how a sustainable and demountable panel could be created.

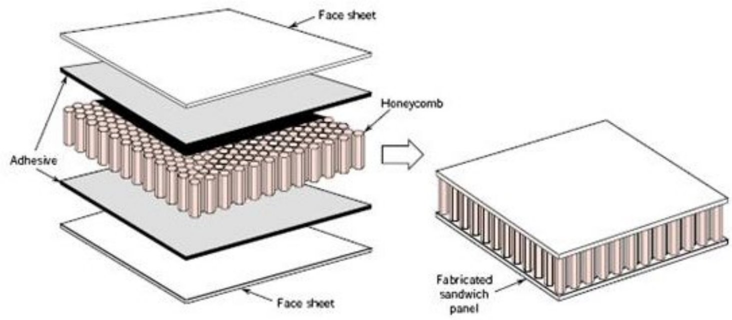


Figure 2: Honeycomb panel construction. Retrieved from GlobalSpec (2020).

Most metal honeycombs are created through the stacking method shown in Figure 3. Adhesive lines are printed on foil sheets, which are stacked and pressed into blocks. The blocks are then cut into slices, which are expanded into honeycomb cores (Corex Honeycomb, 2020). For plastic honeycomb, a continuous production process has been developed, shown in Figure 4. During this process, a extruded film is thermoformed and folded to create a honeycomb core (Pflug, Vangrimde, Verpoest, Bratfisch, & Vandepitte, 2003).

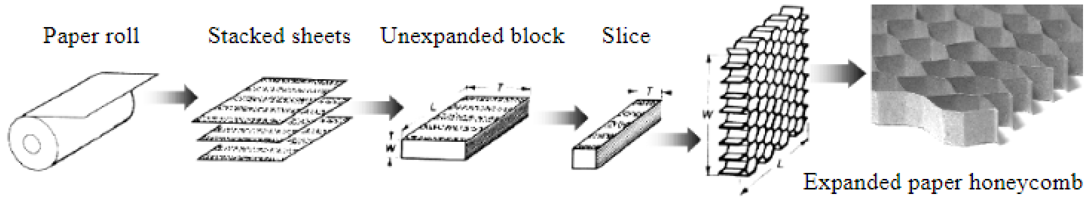


Figure 3: Creating expanded honeycomb cores through sheet stacking. Retrieved from Pflug et al. (2003)

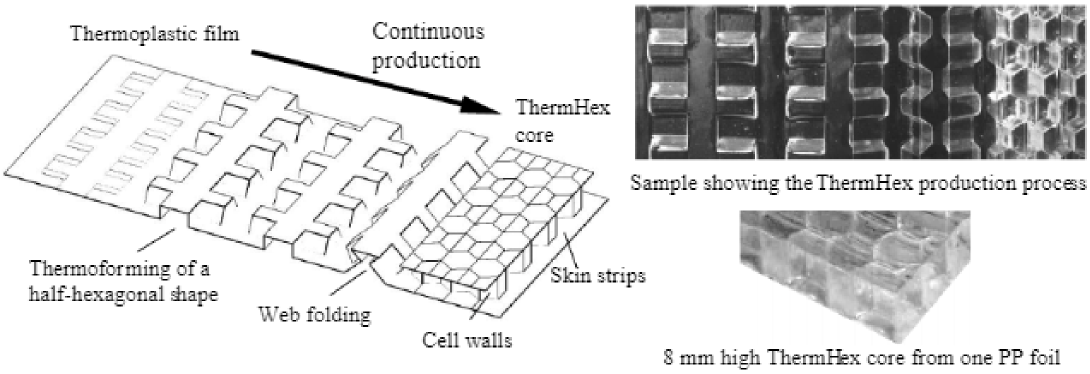


Figure 4: Continuous honeycomb core production. Retrieved from Pflug et al. (2003)

| 1.2.2 Railway approved

EN 45545-2 describes the tests that need to be carried out to ensure that a material is safe for use in trains. When passing the test, the material can be approved for a specific vehicle safety class, which are Hazard Level (HL) 1,2 and 3. These levels are based on how long the trains spend in tunnels and whether they have sleeper trains, where HL3 is the strictest level (DGE - Smart Specialty Chemicals, 2020). This report researched the materials produced by a number of European manufacturers, as described in paragraph 3.1. For aluminium, the honeycombs of four out of six manufacturers are EN45545 approved, of which three at HL3 level and the fourth not reporting a specific level. The two manufacturers that do not report on EN45545 however, do state that they have materials in use in the railway industry. For the plastic honeycombs, three out of four manufacturers mention application of the material in the railway sector and/or train interior, but do not offer any concrete examples. On the other hand, Econcore reports in their rPET material sheet that the material is normally inflammable (building material class B2 DIN 4102-1, respectively D according to EU classification), and that higher grades of fire resistance can be obtained in sandwich elements when using specialized skin materials.

2 DESIGN PROPOSAL FOR A SUSTAINABLE SIDE WALL PANEL

This chapter will elaborate on the proposed design for a sustainable side wall panel, discussing the configuration, usage scenario and implementation roadmap. The design considerations are discussed in the next chapter, and the full list of design criteria can be found in Appendix A.

2.1 PANEL CONFIGURATION

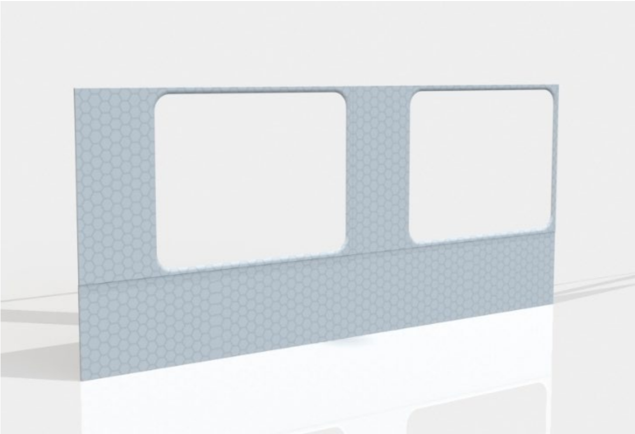
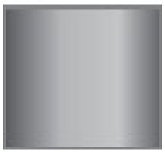


Figure 5: Render of the sustainable side wall panel

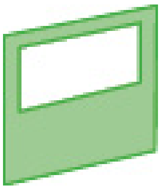
For the panel configuration the materialisation, construction, shape and finish options have been investigated. The chosen options are shown and argued in Table 1. This gave the panel shown in Figure 5. Figure 6 shows an exploded view of the panel, indicating the design decisions regarding the shape. The first indicative measurements for the panel are shown in Figure 8. These measurements were constructed based on the SGMm layout, in combination with creating measurements that are multiples of each other and that optimize the available panel space in order to improve reusability.

Table 1: Most important design decisions for the sustainable side wall panel



Material: Aluminium

Even though aluminium is more expensive, it is already tested and certified for use within the railway industry. Additionally, aluminium is inherently fire resistant, which means that the panels are not disqualified when they need to be reconfigured at the modernisation. Both aspects saves costs, offsetting the increased material price. Using plastics (e.g. PP or rPET) is also an option, but these would need additional fire retardants.

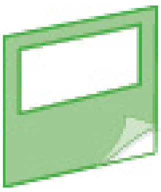


Shape: Flat

A flat shape is easier to reshape, making it easier to reuse in other trains or other repurpose applications. By placing the window off-centre and separating the bottom partition, more usable space is created. Additionally, this means that when the panel is reused in a different train series with a different window shape, only the window section needs to be adjusted or replaced.

Adhesive: Niaga (reversible)

Niaga is an adhesive that can be reversed when applying heat. This means that the skin could be replaced in case it gets damaged. Additionally, Niaga is non-flammable and recyclable. Additional research and testing is needed to get Niaga certified for railway use.



Finish: foil

Foil is easier to apply and works without harmful chemicals. It is also fire resistant, easier to clean, has a longer lifespan and keeps its colour better and for longer. At the end of life, the foil can be removed and recycled. Additional research and testing is needed to get the foil certified, but as the material and adhesive underneath are both fireproof, this is highly likely.

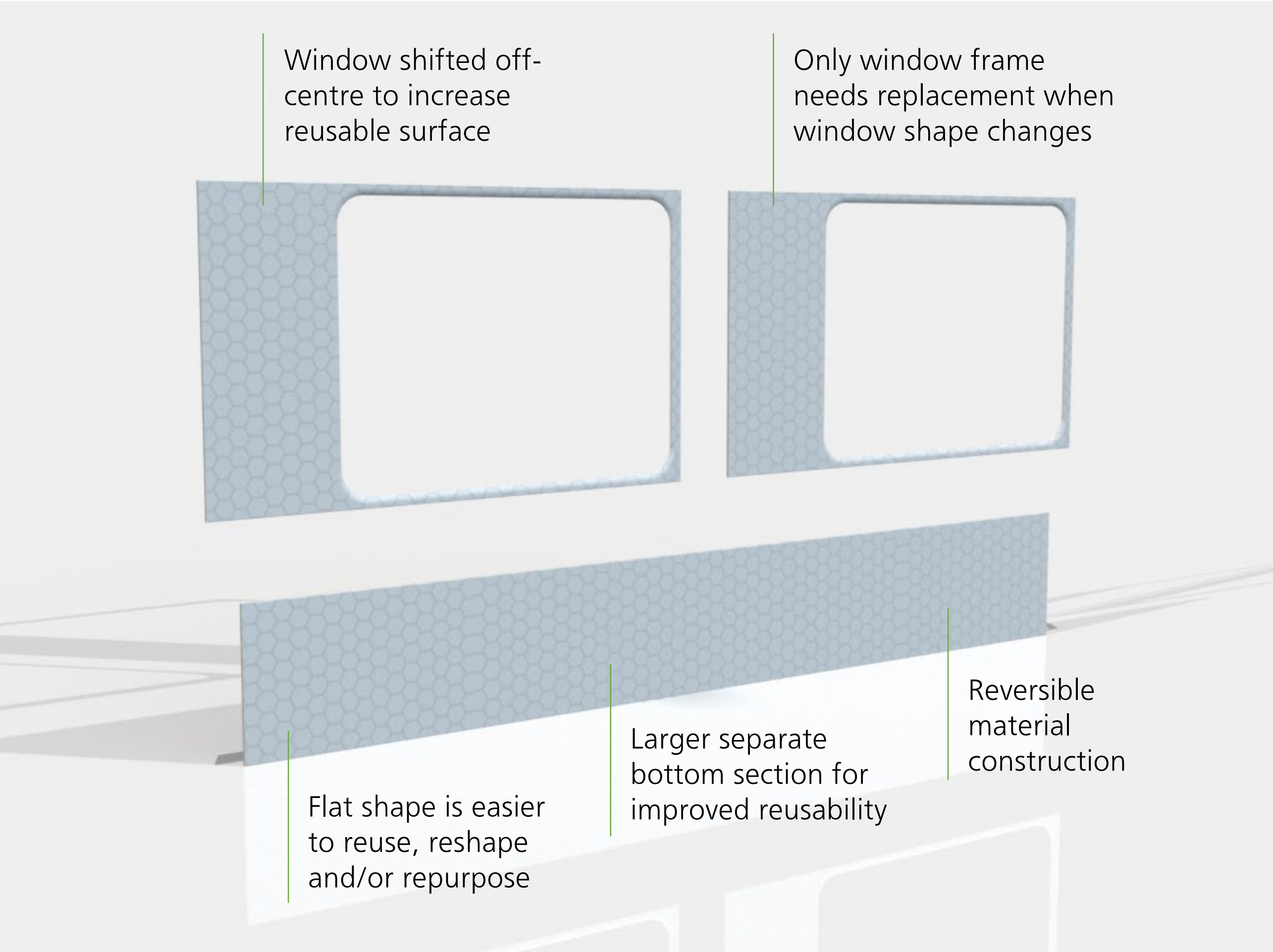


Figure 6: Shape configuration and its benefits

Figure 7: Honeycomb pattern to print on the finishing foil to increase recognisability of the sustainable side wall

Figure 8: First measurement indications

Figure 9 shows a more detailed view of the different material layers. Due to the reversible adhesive and the removable foil, all layers can be separated again. Regarding the foil, one of the remarks for designing a sustainable side wall panel is that it is not as visible to consumers as, say, a train chair. Therefore, attention could be drawn to the side panels by using a foil with a recognizable pattern, such as the honeycomb pattern shown in Figure 7. This way, NS can draw attention to the walls in their communication with travellers, such as: "Have you seen the new honeycomb pattern in the train? Did you know that these walls can be completely disassembled and recycled again after use? Just one of the many ways in which we make our trains more sustainable"

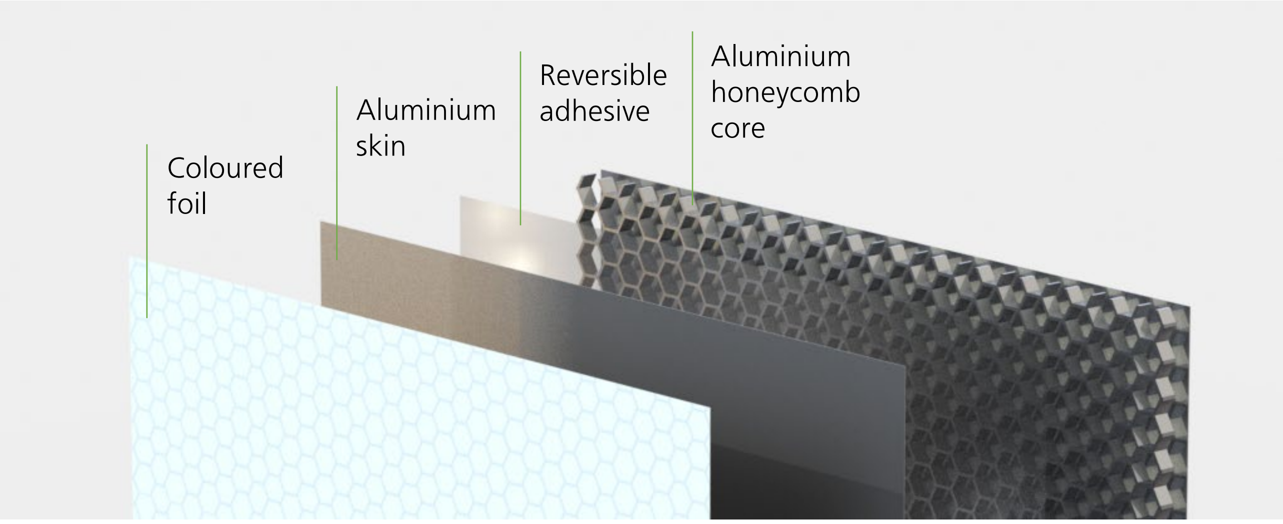


Figure 9: Material composition in exploded view

2.2 USAGE SCENARIO

Figure 10 shows a possible usage scenario for the designed honeycomb side wall panel. As opposed to the composite side wall panel, the honeycomb panel can be reconfigured. This allows the panel to fit the new design of the train when it gets modernised, leading to an increased product lifetime. Additionally, it improves the reusability of the panel in repurpose applications.

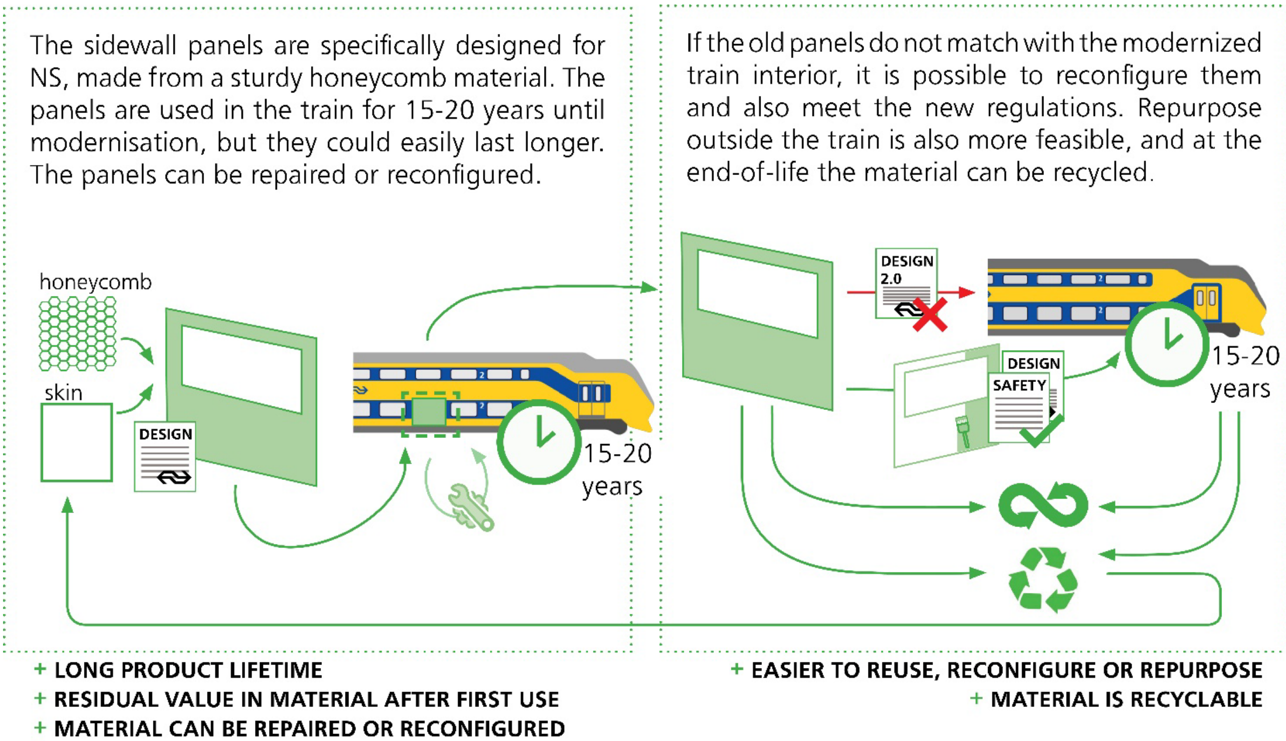


Figure 10: Possible usage scenario of a honeycomb side wall panel.

Paragraph | 3.2.4 investigated multiple repurpose options. Reusing the panels in other train series would be the preferred solution, but this might not be possible due to the tender obligation of NS. The construction industry could also be considered, with the availability of the material as the main attention point: if a guarantee of delivery on a sufficient scale cannot be realized, the panels are per definition not suitable for reuse in the construction industry (Alex Verkuijlen, New Horizons Urban Mining, Personal communication, 2020, July 16). Other applications could be to use the material to make furniture. The bottom sections of the panels is not wide enough to create an adult desktop, but children's desks, side tables, closets or bookcases could be an option.

At the end-life-phase, the panel can be recycled instead of ending up in landfill. The use of removable foil and reversible Niaga adhesive mean that all product constituents can be separated to yield only mono-materials, which enables easier recycling. It is still preferable however to create a panel that limits the amount of different materials used.

2.3 PRODUCT IMPLEMENTATION ROADMAP

The roadmap shown in Table 2 describes the actions and milestones needed to reconfigure the current side wall panel into a circular panel. This design can be developed further in future NS projects, or serve as input or inspiration for the NS circular material handbook for train tenders.

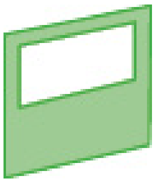
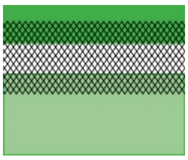
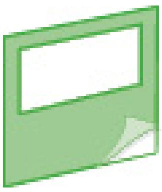
Table 2: Development steps needed before the panel can be implemented

	2020	2025		2030
Material	Build business case for aluminium; Research fire safety for other materials	Make final material choice; Research use of recyclates with panel manufacturer	Implement the use of recyclable and demountable side wall panels in the tender requirements for new trains	Integrate sustainable honeycomb side wall panel into the train
Shape		Optimize shape for specific train type; Pilot test		
Construction	Evaluate application Niaga in train	Certify Niaga for use in trains		
Finish	Certify foil for use in trains			
Longevity	Gather previous modernisation requirements/issues; Discuss reuse of the panel in other trains with train manufacturers			
Repurpose	Discuss panel repurpose with industry/maker partners	Select main reuse application and find partners; Optimize design for reuse		

3 DESIGN CONFIGURATION

The previous chapter gave a proposed design for the panel construction. This proposal was made by researching the different configuration options as shown in Table 3. As all these aspects cover a lot of sub-options and also influence each other, it is difficult to say what the best option is. Therefore, this chapter will give more insight into the considerations made to come to the design proposal.

Table 3: Morphological chart showing all the different configuration options for the honeycomb side wall panel

	Options			
	1	**2**	**3**	**4**
Material	Aluminium  Corex, AluNID, Alucoil	Plastic  Econcore, Armacell, Tubus Waben	Cellulose  Niaga	Alternative skin  (e.g. HPL, GFRP)
Shape	Flat 	Soft bend 	Hard bend 	Complex 
Shaping	None	Machining 	Forming 	Flexible core 
Adhesive	Epoxy 	Niaga 	Thermal welding 	
Lamination	None 	PP film 	PET fleece 	
Finish	Paint 	Foil 		

3.1 MATERIAL

This paragraph compares different material options on performance, circularity and price. Table 4 gives a material data overview of the honeycomb cores. This overview was constructed by combining numerous datasheets from honeycomb core manufacturers within Europe (see Appendix B. The materials included in this data overview are aluminium 3000 and 5000 alloy series, and plastics PP and rPET. There are also honeycombs available constructed from PLA, PC, PEI, but these materials are less suitable for the wall panel. PLA has a temperature resistance between -25 to +55 °C , which is too low for use in the train. PC is aimed at flow efficiency such as refrigerators, Although PEI has good high-temperature resistance and is not as flammable as other plastics, it is very expensive at 15 €/kg (see Table 5). Additionally, DSM Niaga has developed cellulose panels, but these are not yet proven within similar applications, so no comparable data is available. This is why PC, PEI and cellulose are omitted from the overview.

Table 4: Honeycomb material data overview, data retrieved from honeycomb material data sheets from Corex, Cellite, AluNID, Alucoil, Compocel and Alucore, Econcore, Tubus Waben, Nidaplast

	Aluminium	Plastic
Manufacturers/ brands in Europe (selection)	Corex (UK): Corex & Superflex TRB Lightweight structures (UK): Cellite™ AluNID (ES): aluNID ® Alucoil (ES): larcore ® CEL COMPONENTS (IT): Compocel® AL FR 3A Composites (DE): ALUCORE®	Econcore (BE): ThermHex (PP, rPET & PLA) Tubus Waben (DE): Tubus Honeycomb Nidaplast (FR): Nidaplast 8 CEL COMPONENTS (IT): Polypropylene honeycomb
	Performance bare core	
Core material	Aluminium 3000 alloy and 5000 alloy	PP, rPET, (PLA, PC, PEI)
Cell size	1.6 - 19.1 mm	3.0 - 9.6 mm (8.0 mm most common)
Density[1]	Low: 20 - 147 kg/m³ High: 27 - 262 kg/m³	80 - 120 kg/m³
Compressive strength[1,2]	Low: 0.35 - 10.1 MPa / 0.6 - 10.5 MPa High: 0.6 - >14 MPa / 0.85 - >15 MPa *(plain/stabilized)*	PP: 1.2 - 2.95 MPa rPET: 1.4 - 2.5 MPa
Shear strength[1,2]	Low: 0.34 - 5.86 MPa / 0.24 - 3.59 MPa High:0.66 - >6.76 MPa / 0.41 - >3.79 MPa *(L/W direction)*	PP: 0.3/0.5 MPa rPET: 0.6 - 1.1 MPa (*L direction)*
Crush Strength[1,2]	Low: 0.15 - 5.07 MPa High: 0.25 - > 7.09 MPa	
	Panel construction	
Panel size (L x W)	Standard: 2500 x 1250 mm 3000 x 1250/1500 mm. Range: 2000 x up to 18000 mm ± 0.12-30 mm	Standard: 2500 x 1200/1220 Range: 1000 - 2900 mm x 850 - 1400 mm ± 4 mm
Core thickness	Generally ≥ 3-4 mm ± 0.1-0.3 mm	PP: 5 - 100 mm (every tenth) ± 0.35 mm PET: 3.5 - 28.0 mm, PLA: 3 - 30 mm
Foil thickness	Low: 50 μm High: 70 μm	
Skin thickness	Generally 0.5/1.0 mm, up to 5 mm	Comparable to aluminium
Skin material	Various, mostly aluminium	Various, non-specific
	Safety and qualification	
Temperature resistance[(4)]	-40 to +150 °C (but properties will reduce when temperature in-/decreases)	PP: -30 to +80 °C (short-term 140 °C) rPET: -40 to +160 °C (short-term 180 °C)
Fire safety	EN 45545 hazard level HL3	EN 45545, EN 13-501
	Circularity	
Recyclability of material	Recyclable without loss of quality at industrial scale	PP and rPET are both recyclable at industrial scale
Recycled content	No recycled content reported, but it is feasible	PP: no recycled content reported rPET: 95% recycled (post-consumer bottles)
	Price	
Price	Expensive	Less expensive

[1] Low and High depend on the foil thickness that is used to construct the honeycomb core (50 or 70 μm).
[2] Compression, shear and crush strength for most dense version not available.

Material performance

When considering the required strength for the panel, it is important to note that train wall interior panels serve as cladding against the carbody. It is not a structural weight-bearing element, and therefore does not have much regulation on what forces it needs to withstand. The only primary load requirements described in UNIFE TecRec **(FIXME source)** are that it needs to withstand "a concentrated perpendicular load of 2,0 kN applied over a symmetric area of not more than 0.01 m2 which may occur at any position on the surface" and "a pressure of 2,0 kPa applied over the entire surface". Of course, the resistance towards these forces also depends on the shape and skin type of the panels, but both the aluminium and plastic honeycomb should be able to withstand this when considering that the material data in Table 4 only covers the core. These scores will only improve after adding the skin. Another thing to consider is that, as opposed to foam cores, honey comb cores do not have a catastrophic failure mode as illustrated in Figure 11 (Carbon-Core Corporation, 2020).

Figure 11: Foam core (left) and honeycomb (right). Retrieved from Carbon-core (Carbon-Core Corporation, 2020)

More important are the fire safety requirements. Key parameters used here are flame spread, ignitability, heat release, smoke opacity and toxicity. Aluminium is a very suitable material for this application, as it is incombustible and has a melting point around 535 - 639 ˚C (CES Edupack 2019, 2019; Corex Honeycomb, 2020).

Plastics are more troublesome. These materials are highly flammable and the melting point is much lower: 150 - 175 ˚C for PP and 212 - 265 ˚C for PET (CES Edupack 2019, 2019). This means that these materials would need flame retardant additives in order to pass the test. In this case, PEI would be more suitable, as it is self-extinguishing (CES Edupack 2019, 2019).

| 3.1.1 Circularity

The only honeycomb material that reports on circular inflow for the material is the rPET material, which uses 95% post-consumer PET bottles. However, the potential for circular inflow is much larger. Aluminium can be recycled easily without virtually any loss of material quality **[FIXME source],** and PP was also tested to move through multiple recycling cycles with only a small decrease in strength (FIXME Weckström, 2012).

Of course, recycling is only the last stop for the panel. It would be more interesting to see how the panel could be reused or repurposed. Both aluminium and plastic honeycomb panels can be reshaped after use, which means they could be reconfigured to fit a new train shape or a new application outside the train. For reuse, it should be looked into what material would better fit the changing train environment, while also considering the product lifetime. For repurpose outside the train, the market size and interest for used panels should be looked into to see what material type would be the most promising to repurpose.

| 3.1.2 Price category

There is not much openly available about the price of the panels. Corex does have a webshop to order panel testers, but this is not representative for the price of the final product. To give an indication of the price, the material prices per kg can be compared. These prices were retrieved from CES Edupack 2019 (CES Edupack 2019, 2019), Level 2 (and Level 3 for PEI, unfilled).

Table 5: Material prices per kg

Aluminium: 2.02 – 2.18 €/kg	PP: 1.19 – 1.23 €/kg PET: 1.13 – 1.31 €/kg	*PLA: 2.42 – 3.18 €/kg* *PC: 2.76 – 3.03 €/kg* *PEI: 15 €/kg*

The price overview in Table 5 shows that aluminium is generally pricier than PP and PET, but cheaper than PLA, PC and PEI. Ward Mosmuller of DSM Niaga confirmed that aluminium panels would be considerably pricier (Personal communication, 2020, July 28). The production process is also of large influence. Honeycombs that can be produced continuously are much cheaper to produce, as stated by Econcore for their PP honeycombs (Econcore, n.d.).

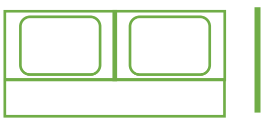
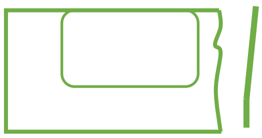
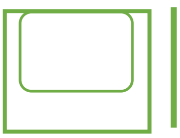
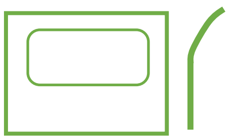
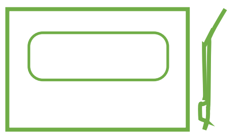
3.2 SHAPE

This paragraph will look at the shapes for train interior side panels by comparing current train interiors. It also includes the implications of choosing a specific panel shape.

| 3.2.1 Train interior fashion

Table 6 gives an overview of the walls in current train series. The newer Flirt and SNG are omitted from this overview, as no drawings or side wall drawings could be found in the database during this project. The train wall type overview gives an indication of the shape of the interior wall. This shape is created by tracing the contours of the front view and side view of a side wall in the technical drawings retrieved from Infor PLM (NS database). Details were simplified while tracing, such as small radii around windows or corners or hooks for attachment. Any bends of the side profile to the right are towards the train interior, and vice versa. Also important to note is that there are many different panel variations in a single train type. However, this approach is sufficient when only looking at the overall panel shape. The measurements (rounded to tens) indicate the size of the panel front view, which is the composite panel section around one window (except for SGMm) from the floor up to the luggage racks.

Table 6: Analysis of train wall types and measurements in current train fleet

SGMm  Flat ~3100-3400 x 1510	**ICMm/ICRm**  Soft bend ~2400 x 1370 mm	**SLT**  Flat ~2220 x 1330	
DDZ (lower floor)  Flat ~1630 x 1410	**DDZ (upper floor)**  Hard bend ~1620 x 1220	**VIRM/VIRMm (lower floor)**  Flat/complex ~1900 x 1470	**VIRM/VIRMm (upper floor)**  Hard bend/complex 1930 x 1330

The overview in Table 6 shows that most sidewall panels have a quite simple shape. The main fashion trend is to build flat or soft bend side walls for single deck trains, and flat and hard bend side walls for double deck trains. Only the VIRM/VIRMm has a complex side contour, as this train type makes use of garbage bins that are placed within the side wall. Regardless of whether this contour could be achieved with honeycomb panels, it is preferred not to do so as it would only increase costs. Additionally, as newer train types such as Flirt and SNG do not make use of these type of garbage bins, it is unlikely that this contour would be needed.

When looking at the panel measurements, it can be seen that most fall within the 2000 x 1500 mm range. The ICMm/ICRm and SLT are only slightly wider, and SGM has wider panels as it has a separate strip running beneath two windows. Standard honeycomb panel sizes are 2500 x 1250 and 3000 x 1250/1500 for aluminium and 2500 x 1200/1220 for plastic honeycombs (see paragraph 3.1). Not all panels therefore fit the standard panel size, but it is very feasible to create the desired shape without needing extensive custom sizing.

| 3.2.2 Flat panels for fabrication ease

A side note to consider when choosing the shape is that flat panels are easier to press and to finish and/or foil. This is because a flat panel can be placed on a vacuum table, whereas curved panels would require special clamps or moulds to be secured (Niaga, personal communication, 2020, July 28). This could be partially counteracted by making the backside of the panel flat, so that it can be clamped via vacuum suction on that side. The added benefit for creating flat and non-complex shapes would also be that it's easier to reuse or repurpose in another application.

| 3.2.3 Bended/complex panels for design and space optimisation

The benefits for choosing a bended or complex panel shape would be that the side wall can be tailored to the design of the train and the car body shape. This is especially important when considering double decker trains, as using flat walls could considerably impact the available space in the train. Still, the fabrication possibilities for the panel should be taken into account to limit the production costs of the panel. This means a bended panel shape is preferred as opposed to complex.

| 3.2.4 Second product lifecycle within and outside the train.

The reuse of the panel should not be limited just to train modernisation. It would be more interesting to consider a second lifecycle as well as a prolonged first use cycle. This could either be in another train series, or within another industry. The shape of the panel can then be adjusted to meet the requirements of the envisioned second lifecycle. Below, reuse of the panel in other train series, the construction industry and furniture industry is discussed.

Considering the reuse of panels in other train series, the SGM configuration seems an interesting choice. By running the side walls in two sections, larger panel pieces can be used to easier fit new a new train. The panel shape would preferably be flat or softly bended, as this shape is easier to reshape to fit a new train shape. Separating the window frame part means that when fitting the panels in other trains with a different window size, only the top partition with the windows would need replacement instead of the whole panel. Of course, this could also be achieved by cutting off the window section, but this would lead to a smaller bottom partition (only one-window width instead of two).

Although reusing the panels in other train series would be the preferable application, it is uncertain whether this option can be legally realized as NS is bound by tender contracts for the building of new trains. Therefore, it is recommendable to also consider repurpose applications outside the train. To gauge interest for reusing the panels in the construction industry, I contacted New Horizons, an urban mining collective that harvests materials from buildings for reuse. From director Alex Verkuijlen I received the reply that the reuse possibilities for honeycomb materials depend on many factors, such as listed in Table 7 (Personal communication, 2020, July 16). From his reply there can be concluded that having a larger bottom section as described above would also be more interesting as this increases the size of the available material. However, the availability of the material would be an issue. More research and collaboration would be needed to find how this issue can be overcome. Verkuijlen recommended me to contact their partner Stiho for further help.

Table 7: Factors to consider when designing for reuse in the building industry

Material	What material is it made from? What is the footprint?
Measurements	The building industry is used to work with big measurements and tailor those to size. How smaller the available material, the smaller the amount of possible applications
Availability	If the material is made specifically for trains, the availability will be very low. It will per definition not be suitable, as the effort for convincing the building industry to use the material will not outweigh the guarantee of supply.
Compatibility	How does the material react or how does the material processing compare to the other building materials used?

Another application with a lower production requirement would be to reuse the material as a desktop. NS already has a collaboration with Gispen to produce desks out of train ceiling plates. When looking at the measurement requirements for a desk, ergonomic desk norm EN 527-1 describes that an ergonomic desk top is at least 80 cm deep and 120 cm wide, with an ideal width of 160 cm. As can be seen in paragraph | 3.2.1, all current wall panel measurements have a width of minimally 160 cm. The depth of the desk is more problematic however. The bottom section of the SGMm panel has a height of roughly 50 cm, which is too small for use as a desktop. The other wall panels don't have much wider bottom sections. A possibility would be to produce a children's desk: the measurements of these desks at IKEA vary between 73-128 cm width and 50-58 cm depth (IKEA, 2020). Another option would be a side table, book case or closet. However, additional research and collaboration would be required to see if sufficient market would be available to offset the furniture outside NS.

As found in this section, there is not yet a ready-to-go application that fits the side wall panel. Still, generally seen it would be easier to make the width of the bottom partition a multiple of the height, for example 300 x 50 cm. This way, it becomes easier to create square or rectangular shapes for furniture with only minimal offcuts. Facilitating reuse of the material between the windows is more tricky as the space between the windows is generally limited; around 50-70 cm wide and around 85 cm height. Also for most series, except ICMm/ICRm, this space is divided in half by the panel edges. This makes this section less interesting. However, combining the SGMm and ICRm/ICMm configuration as shown in Figure 12 on the left would optimize the available material size for that area. This way, for example a shelf for in a closet or book case could be created from this material section. Other shelves could be created from the wall section above the wall panel behind the luggage rack or by cutting up the bottom section. Another configuration option that minimalizes the waste generated when a window shape is changed would be placing separate panels between the window frames as presented in Figure 12 on the right. However, this would increase the amount of mounting profiles and thus material and labour needed, resulting in higher costs.

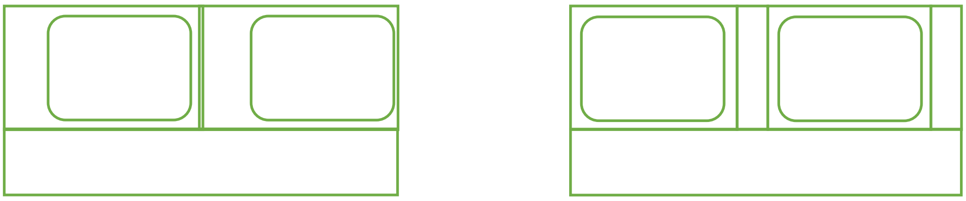


Figure 12: Panel configurations that)combine SGMm and ICMm/ICRm layout (left) and minimize window frame area (right)

3.3 SHAPING

As the shaping is highly dependent on the chosen shape, this paragraph will discuss both the shaping possibilities for both material types and the pros and cons for each shaping option.

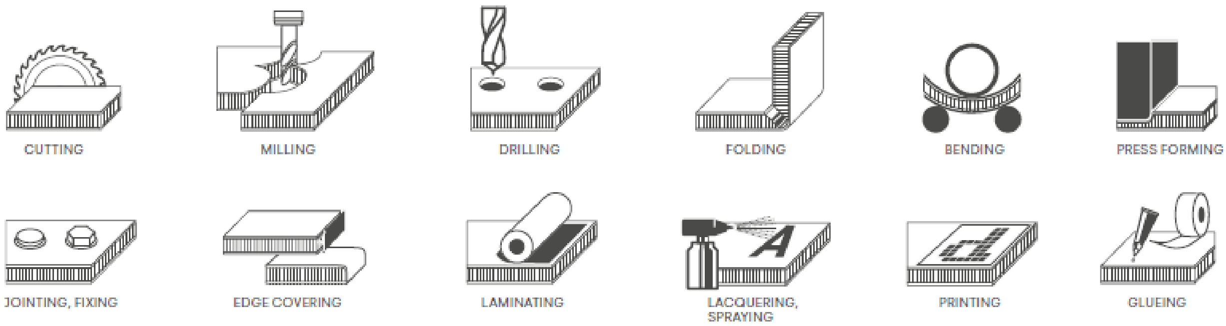


Figure 13: Shaping options for aluminium honeycomb panels, retrieved from the Alucore brochure (3A Composites, 2019)

Aluminium honeycomb can be machined to form a complex surface with the use of high speed routers. Some single curvature contours can be machined on to an unexpanded slice before expansion (Corex Honeycomb, 2020). Figure 13 shows that additionally, panels can also shaped using forming methods such as folding, bending, and press forming. Another option is to use flexible aluminium core, such as Superflex by Corex. By adapting the cell geometry, the aluminium honeycomb can bend and flex. The resulting flexible honeycomb has the same properties as the standard hexagonal cell shaped aluminium honeycomb, and can be used for curved panels, spherical, cylindrical and organic shapes (Corex Honeycomb, 2020). Of course, shapes can also be created by joining multiple panels/shapes, for example through the use of mounting profiles.

For plastic honeycombs the reported shaping options are mainly cold moulding and warm moulding. Cold moulding allows honeycombs with low thicknesses to be shaped in large radii at room temperature. The shaping is done by applying pressure or vacuum on a sandwich element that has been placed and fixed into a shaping tool. The new shape is retained by hardening the resin or adhesive (TUBUS WABEN GmbH & Co. KG). For warm moulding, the thermoplastic honeycomb (with or without thermoplastic skin) is first heated through an oven, infrared radiation or heated mould. Then, the panel is shaped in the mould, after which it is cooled. The process is reversible, and can be repeated through reheating and reshaping, as long as thermal decomposition is not caused in the material due to overheating. Additionally, the temperature should allow moulding but not melting as this will cause the honeycomb to lose its structure (TUBUS WABEN GmbH & Co. KG; Plascore, Inc., 2018). To summarize, the options are to use no or minimal shaping, machining, forming or a flexible honeycomb to achieve the desired shape. Below, the pros and cons for these options are discussed.

| 3.3.1 No or minimal shaping

If the panel is flat, it will require no or only minimal shaping. Examples of shaping that can be done for these panels are rounding the edges towards the window, or creating a ridge for holding the panel in the profiles that fit the panel against the car body of the train. These shapes can be created using cutting or milling techniques on either expanded or unexpanded slices.

+ Minimal effort
- Limited form freedom

| 3.3.2 Machining

Expanded and unexpanded aluminium panels can be machined to create curves. However, when large curvature contours are created, a lot of material will have to be removed, leading to large material losses. There is no mention of machining contours for plastic honeycomb cores.

+ Some form freedom
- Machining large curvatures means more material loss.

| 3.3.3 Forming

Both aluminium and plastic honeycombs can be shaped through forming, bending and press forming. As this is done after the skin is added, the material losses are reduced. However, the structural and/or temperature impact of the process should be taken into consideration.

+ Great form freedom
+ Reduced material losses
+ Easier to add skin
- Possible impact one panel performance

| 3.3.4 Flexible core

By using flexible aluminium honeycombs, extensive form freedom can be achieved, such as curved panels, spherical, cylindrical and organic shapes. However, this will likely come with a higher price tag.

+ Extensive form freedom
- Likely more expensive

3.4 ADHESIVE

This paragraph will discuss the adhesive options that adhere the skin to the honeycomb material. For this, the material, performance, reversibility and recyclability will be discussed.

| 3.4.1 Adhesive type

For honeycomb panels, there are multiple adhesive types that can be used. Examples of common types are structural adhesives such as polyurethane or epoxy, or hot melt adhesive films (Nidaplast). The standard type for most adhesives is epoxy (Ruben Rulf, personal communication, 2020, June 29). For honeycombs, it is mostly a high performance epoxy film adhesive (80° C service temperature) as this is easier to adhere to the honeycomb (**Cellite FIXME**). However, epoxy is a toxic substance, which should be avoided when designing for sustainability (Niaga, personal communication, 2020, July 28).

Another interesting adhesive is Niaga due to its reversibility (see section | 3.4.3). This adhesive is made from polyester. It is not yet used for aluminium or plastic honeycombs, but it has been used for cellulose honeycomb panels, carpets and mattresses (Niaga, personal communication, 2020, July 28).

For plastic honeycombs, welding is also an option for attaching skins to cores (**Tubus Waben FIXME**). However, this means that the layers cannot be separated again after use. It should therefore only be applied when the core and skin are made of the same material to ensure that the panel can be recycled as a whole.

| 3.4.2 Adhesive performance

In general, tough and resilient adhesive systems are preferred as opposed to a brittle-hard adhesive system, as resilient systems score better in so-called peel tests, which test the skin-core adhesion. The common adhesives have already proven themselves regarding strength and use in honeycomb panels. For Niaga, additional testing would be required to see if it would be suitable for use within the train. However, as it is also used in panels and mattresses, it is highly likely that it will have sufficient strength. Furthermore, Niaga is made from polyester, which doesn't burn or develop black smoke, thus reducing suffocation dangers and increasing its fire safety performance. It is uncertain what the performance of welding is, but if this is done well, the joint will become part of the material. It will therefore be unlikely to yield to peeling or to have a different fire safety degree than the core/skin material.

| 3.4.3 Adhesive reversibility and recyclability

Epoxy, other common adhesives and welding all form (near) irreversible connections. This means that the only way to separate the main materials will be by pulling them apart with considerable force or by cutting them loose. With common adhesives, this will mean that there will be residues left behind on the material, which impacts the recyclability. Welds are even more difficult to separate, again leading to material residues if the panel is not made from mono-materials. Additionally, epoxy adhesives are non-recyclable (Niaga, personal communication, 2020, July 28).

Niaga on the other hand can be reversed and by the application of heat/energy. This means the panels can be readjusted or reconstructed if needed, and that parts of the product can be replaced. Also, when separating the panels, Niaga leaves no residues to ensure clean recycling. Also important to consider is that the best recyclability is achieved by creating mono-materials, as separation is difficult and expensive. In case of Niaga, the adhesive is made from polyester, so combining with polyester would give a mono-material (personal communication, 2020, July 28).

3.5 LAMINATION

Lamination of the cores is often mentioned in combination with (mainly plastic) honeycomb panels. This lamination is done by attaching and (thermally) connecting a PP film and/or polyester fleece layer to the honeycomb core (see Figure 14). The PP film is applied when using liquid resins. It prevents resin from leaking into the honeycomb, safeguarding uniformity of the mechanical performance and keeping the honeycomb free of resin. The fleece layer is used as an adhesive for further processing by creating a surface for improved bonding with the core when attaching the honeycomb panel skins (TUBUS WABEN GmbH & Co. KG, n.d.; EconCore N.V., 2020).

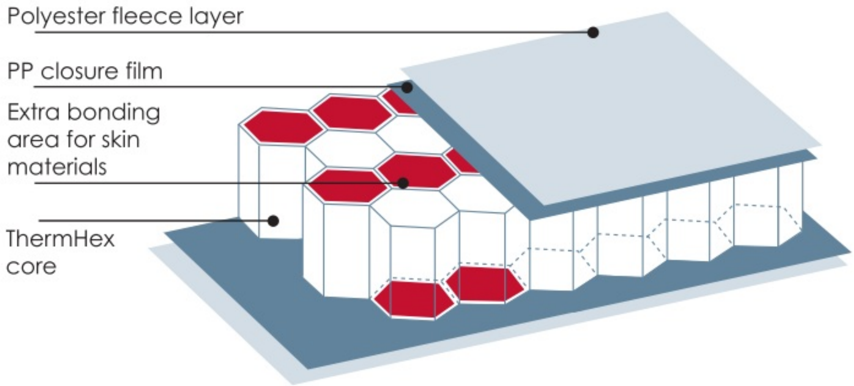


Figure 14: Application of lamination layers, reproduced from EconCore (EconCore N.V., 2020)

When creating a circular product, it is important to use as little material as possible and to create reversible connections (Niaga, Personal communication, 2020, July 28). As using a resin glue is non-reversible, it is not recommendable to use this glue type, which means a PP film layer has little use. Niaga also confirmed that no additional lamination is required when using their glue (Personal communication Ward Mosmuller, Niaga, 2020, July 28). As the fleece layer also increases material use, it should be avoided. Lamination should only be used when it improves product circularity, for example by reducing use of materials/adhesives or improving ease of disassembly.

More interesting than using lamination would be to consider optimal application of the adhesive. Generally, for the sake of convenience, the adhesive was applied to the skin and the honeycomb was placed in the adhesive; this is also called embedding. However, this means more than 90% of the adhesive is in the wrong place, which increases adhesive costs and unnecessarily raises the flammable mass. In most cases the bond strength is impaired too. It is therefore important that honeycomb edges are properly embedded in the adhesive and the adhesive itself is ductile. A system to improve the adhesion is to use a slit adhesive film that expands after heat activation, shown in Figure 15. Application in this manner concentrates the adhesive around the honeycomb edges, thus limiting the amount of glue used. Additionally, the slit film system yields much better peel strengths and similar flexural strength and creep resistance compared to conventional embedding. The challenge is to match the adhesive network to the honeycomb structure. Although process optimisation is time-consuming for industrial use, the results make it worth-while (Jud, 2012).

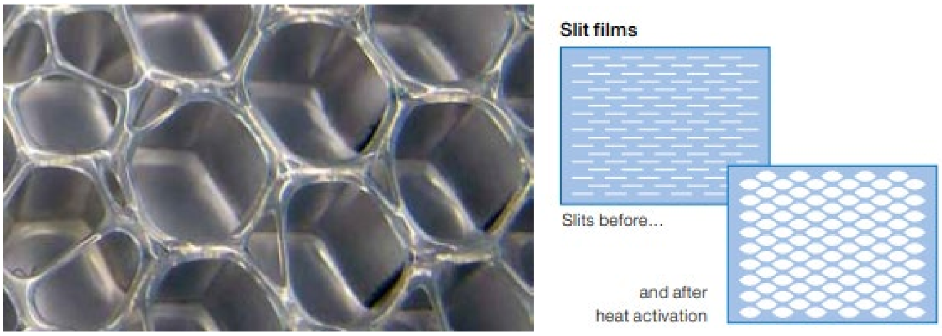


Figure 15: Film adhesive concentrated around the edges of aluminium honeycomb (left) and slit film expansion (right)

3.6 FINISH

Traditionally, paint is used to colour the side wall panels in the train. A different way to finish the wall panels would be to use foil. Aalse Dijkstra, cleaning engineer of NS, informed me on the current application of foil in NS trains (Personal communication, 2020, July 15). Below, the differences of paint and foil regarding application and reconfiguration, fire safety, cleaning and vandalism, and sustainability will be discussed.

| 3.6.1 Applying and reconfiguring paint and foil

Painting is a laborious process which can yield toxic fumes. A bio-based paint such as Decovery could be considered to improve sustainability, but even then painting is an irreversible process. The only way to remove paint is by sanding it off. This yields paint dust, which could be seen as micro plastics (Ward Mosmuller, Niaga, Personal communication, 2020, July 28). Additionally, the dust can be toxic, for example when the paint contains chromium-6. Also, as stated in section | 1.1.1, sanding and repainting is often not possible at modernisation, which means the whole part cannot be reused.

The foil, made of polyester, is currently mainly used on train exteriors. It has also been applied in the interior of some trains, such as in toilets and on the partition walls (between seating and balcony) of the ICM train. The foil can be applied easily, and has no shape restrictions. After use, the foil can be removed again. On the exterior of trains, often a transparent foil is used over a paint system. This is done on recommendation of the manufacturer for the preservation of the train. However, there are also trains in Norway that do not use paint underneath the foil (Aalse Dijkstra, NS, Personal communication, 2020, July 28). Additionally, the train interior is for example not exposed to rain. Using a coloured foil would therefore be preferably to reduce the materials and chemicals used. Additionally, this means that readjusting the panel appearance at modernisation could be as easy as swapping the foil for another colour or pattern.

| 3.6.2 Fire resistance of paint and foil

Paint is currently used, and adheres to safety regulations due to the right additives.

For the interior use of foil, fire safety is the biggest reason why it is not applied yet. It has taken 20 years before using the foil on train exteriors was permitted. This is not due to the fire safety of the foil itself: the polyester foil is not flammable but self-extinguishing, and only leaves a small burn mark. Instead, the issue is that paint, wood or other materials underneath the foil keep burning (Ward Mosmuller, Niaga, Personal communication, 2020, July 28). This could be avoided by not using paint and choosing a non-flammable material for the honeycomb skin.

| 3.6.3 Panel cleaning and vandalism

When applied to the exterior, paint is quite high maintenance. It needs to be washed often, and once every sixty days the paint needs to be cleaned with oxalic acid, which is a harmful substance. Additionally, paint is very vulnerable to vandalism such as graffiti (Aalse Dijkstra, NS, Personal communication, 2020, July 28). Cleaning graffiti means that the train is taken out of service, and also a lot of materials and chemicals are used to remove it. The train is placed on an absorption layer while the graffiti is washed off with aggressive chemicals. Afterwards, the whole layer is thrown away (Ilse de Vos van Eekeren, Personal communication).

A foil exterior on the other hand has to be cleaned only half as much, and it does not need treatment with oxalic acid. When cleaning graffiti, the train still needs to be taken out of service, but cleaning graffiti off foil takes only half the time (Aalse Dijkstra, NS, Personal communication, 2020, July 28). When translating these insights towards interior use, foil would be easier to clean and could use less aggressive cleaning agents.
The only way that the foil was damaged during testing was with a knife, but almost no finishing systems are resistant to this. Also, no knife damage has been encountered during tests with foil in train toilets (Aalse Dijkstra, NS, Personal communication, 2020, July 28).

| 3.6.4 Longevity and recyclability of foil and paint

To compare the lifetime of both paint and foil, it is interesting to look at the ICMm trains. Twelve years ago, most ICMm trains were put in foil, but a couple remained painted in order to compare. In those twelve years, the foil has not suffered any damage or loss of colour. The painted trains on the other hand have been repainted three times already (Aalse Dijkstra, NS, Personal communication, 2020, July 28). This makes foil the more durable option. Also, when considering recyclability, paint is also not the preferred option. As stated in section **Fout! Verwijzingsbron niet gevonden.**, paint can only be removed through sanding. The resulting dust is not recyclable. The foil on the other hand can be removed, and is taken back by the supplier for recycling (Aalse Dijkstra, NS, Personal communication, 2020, July 28).

3.7 SUMMARY

Table 8 shows an overview of the most important findings for each option.

Table 8: Summary of findings for each configuration option

Category	*1*	*2*	*3*	*4*
Material	Aluminium	Plastic		
	+ Non-flammable + Already applied in trains - Expensive	+ Cheaper - Needs additives for required fire resistance - Not yet applied in trains		
Shape	Flat	Soft bend	Hard bend	Complex
	+ Easier to produce, reuse and repurpose - Limited form-freedom	+ Side wall can be tailored to train design/shape - Increased production costs	+ Side wall can be tailored to train design/shape - Increased production costs	+ Side wall can be tailored to train design/shape and integrated parts - Highly increased production costs
Shaping	No/minimal	Machining	Forming	Flexible core
	+ Minimal effort - Limited form freedom	+ More form freedom - Material loss	+ More form freedom - Affects skin integrity	+ Extensive form freedom - Possibly expensive
Adhesive	Epoxy	Niaga	Thermal weld	
	+ Industry standard - Irreversible and non-recyclable	+ Reversible and recyclable - Needs testing	+ No additional materials used - Irreversible	
Lamination	PP film	Fleece	None	Optimal glue film
	+ Prevents resin leaking into core - Adds materials	+ Improves bonding (surface) of the core - Adds materials	+ No materials used	+ Improves core adhesion and performance - Optimization process needed
Finish	Paint	Foil		
	+ Industry standard - Irreversible and non-recyclable	+ Durable, reversible and recyclable - Needs testing		

APPENDIX

A DESIGN CRITERIA

Below is a list of design criteria for the sidewall design. This list is constructed from my own estimates and insights through involvement at NS, and by selecting the relevant criteria from regulation documentation such as TecRec, as cited in the list. This list has not been validated and the design has not been checked against the requirements, but it helped me to get a better view on which aspects were relevant and on what requirements are currently in place.

1. Performance
    1.1. The wall product must allow mounting onto the car body shell.
    1.2. The wall product design must (be able to be adjusted to) allow the mounting of interior elements (e.g. seat elements, luggage racks). This includes both sufficient strength and stiffness as well as the fitting of inserts for mounting.
2. Environment
    2.1. The product must be able to function between general temperatures between 19 and 26 degrees.
    2.2. The product must not be significantly affected by cabin temperatures between 0 and 40 degrees Celsius.
    2.3. The product performance and colour must not degrade significantly/critically under the influence of general cabin humidity.
    2.4. The product performance and colour must not degrade significantly/critically under the influence of (indirect) sunlight.
    2.5. The product must not leach hazardous substances to the environment in the prescribed production, usage and end-of-life processing scenarios.
3. Life in service/Product lifespan
    3.1. The product is a non-loaded passive train interior part, so it will see low usage intensity.
    3.2. The product must have a general lifespan of 15-20 years.
    3.3. The product must be able to be produced for as long as the train is in use.
4. Maintenance
    4.1. The product must be able to remove from the car body to allow servicing of the windows.
    4.2. The product must be able to be dismantled from the car body in the general maintenance and service workshops of NS.
    4.3. Dismantling the product from the car body should take less than 10 minutes with two people.
    4.4. The product must be able to be cleaned with water and general cleaning agent.
5. Target product cost
    5.1. The cost of the product must not exceed ???
6. Transport
    6.1. The products must be able to be transported with an efficiency of at least 50%.
    6.2. The products must be able to be withstand general transport and handling with minimal packaging. This includes both functional and cosmetic/visual effects.
7. Packaging
    7.1. The products must be delivered with minimal and/or reusable packaging.
8. Quantity
    8.1. The amount of products produced is the amount required for the train production and for the necessary spare stock. This will be around 12 products for a single-deck train car and 23 products for a double-deck train car, plus negligible stock. With generally 500-700 train cars in a train series, this means a batch size of between 6000 to 16100 products.
9. Production facilities
    9.1. The main production of the product will be outsourced; only minimal adjustment should be made in the maintenance workshop when installing a product (e.g. when replacing/repairing).

10. Size and weight
    10.1. The product thickness must not exceed the 20 mm width (excluding protrusions for the mounting of interior elements) to allow enough space for other interior elements.
    10.2. The product weight must not exceed the current product weight of … kg?
    10.3. The product must fit within the expected train cabin interior measurements.
    10.4. The space normally used by seated or standing passengers or staff shall be considered to be limited to a maximum height of 1950 mm above floor level in standing areas and up to a maximum height of 1680 mm above floor level in seating areas. In seating areas the assumed seat width shall be at least 450 mm centred relative to each seat. The upper corners of the seated space envelope may be assumed to be radiused to a maximum value of 225 mm. *(NOTE: These parameters are based on the PRM TSI requirements for headroom in seated areas.)*
11. Aesthetic, appearance and finish
    11.1. The product must fit in the envisioned future train design aesthetics.
    11.2. The product must have a timeless/neutral appearance.
    11.3. The product must have a (visually) smooth surface for easy cleaning.
12. Materials
    12.1. The product must make use of lightweight materials.
    12.2. The product must consist of materials that are able to be recycled at the end of life using conventional (industrial scale) process methods.
    12.3. The product must not make use of any hazardous materials, such as asbestos, chromium-VI and any other materials that are on the REACH list or in any other way forbidden, or expected to be forbidden soon.
    12.4. Standards, rules and regulations
    12.5. The product and mounting profile must make use of standard mounting hardware (screws/nuts and bolts/inserts/etc.).
13. Ergonomics
    13.1. Max. 2 people should be needed to lift the panel.
    13.2. Max. 2 people should be able to mount the product with both an ergonomic working posture.
14. Reliability
    14.1. The product must not fail under general usage conditions.
    14.2. The panel must survive a fall of up to 1 m.
    14.3. The panel must fail in a consistent way in expected collision scenarios.
15. Storage
    15.1. The products must be able to be transported with an efficiency of at least 50%.
    15.2. The product must be able to be stored in general storage conditions (no additional heating/cooling and ambient atmosphere) without product degradation.
16. Testing
    16.1. The product must be tested for fire safety as described in the EN 45545-2 standard [source, also check with EU website].
    16.2. The following tests are used to measure how the product compares to the product requirements.
        16.2.1. TO1 Oxygen Index
        16.2.2. 03 Flue gas density
        16.2.3. T12 Smoke toxicity
    16.3. Key parameters that are measured include flame spread, ignitability, heat release, smoke opacity and toxicity. Having passed the tests, the product is given approval according to EN 45545-2 for use in trains.
    16.4. The product must be tested for primary load.
    16.5. The product must be tested through a secondary impact review as described in UNIFE TecRec. The secondary impact review should be based on an examination using the definitions in this document and recommended criteria set out in 6.2.2.

16.6. Areas which are accessible to passengers and staff in normal service shall be subject to a secondary impact review to examine the general features and detailing of the vehicle interior considering the risk of injury due to secondary impact against surfaces or items.
16.7. The design and installation of the interior shall be examined for potentially aggressive features with respect to:
16.7.1. Exposed corners and edges.
16.7.2. Recesses.
16.7.3. Protrusions.
16.8. The following may be omitted from the secondary impact review:
16.8.1. Items shielded by another item when potential impact is considered in longitudinal, lateral or vertical directions.
16.8.2. Items which cannot be contacted by a 100 mm diameter sphere.
17. Safety
17.1. The product must adhere to the EN 45545-2 standard fire safety standards for train interior.
17.2. The product must adhere the primary load requirements as described in UNIFE TecRec,
17.2.1. Interior doors (with the exceptions of hinged doors which do not lock or latch) and partitions, in any areas of such items which are not glazed, shall withstand the following proof loads applied independently:
17.2.2. A concentrated perpendicular load of 2,0 kN applied over a symmetric area of not more than 0.01 m2 which may occur at any position on the surface
17.2.3. A pressure of 2,0 kPa applied over the entire surface.
17.2.4. The positions where the concentrated loads are the most critical shall be determined. The analysis shall consider the maximum stresses in the door structures or partitions due to bending and stresses at mounting points and any other locations where stress concentrations could occur due to local details or changes in shape or form.
17.2.5. The proof loads shall be applied to partition faces which are fully or partly exposed to the vehicle interior. Where both faces of a partition are exposed to the vehicle interior the proof loads shall be applied to each face independently.
NOTE 1: The proof load requirements do not apply to areas of partitions which are completely shielded by other items, for example seats or luggage stacks. A partition is required however to withstand any loads transferred to it by such items.
17.2.6. Where partitions are fitted with trim panels, it is permissible for the specified proof loads acting on the trim panels to be considered as ultimate loads for these items.
NOTE 2: Where trim panels are used, the specified loadings are to be treated as proof loads by the underlying structure of the partition assembly. In terms of secondary impact, provided that hard spots or abrupt changes in stiffness can be avoided, the implied panel flexibility would generally be considered beneficial to passengers in the event of a collision.
17.2.7. Where seats are attached directly to partitions or the seat backs are placed sufficiently close to partitions, luggage stacks or other seat backs to allow them to be contacted under proof load conditions, the partition, luggage stacks or adjacent seats shall withstand without significant permanent deformation loads that are transferred from the affected seats when subjected to the specified seat proof loads.
17.3. In case of a collision, the product must resist deformation or deform/collapse in a controlled way that poses no risk to the passengers and staff inside the train.
18. No excessive deformation towards the interior of the train;
19. No forming/exposing of sharp edges
20. The product must adhere to the following requirements for interior features with injury potential, as described in UNIFE TecRec.
20.1. Exposed edges in rail vehicle interiors
20.1.1. Only exposed rigid edges which can be contacted by a 100 mm diameter sphere shall be considered. Edges of components which are not directly exposed (for example

sheet metal fabrications beneath seats) shall be de-burred or chamfered to give smooth edge profiles.

- 20.1.2. In differentiating between an external and an internal edge, where a panel edge fits up against another element to form a step or a recess that edge shall be considered to be internal (for example where rebated panel joints are used).
- 20.1.3. A rigid edge shall be considered to be one using material with a Shore A hardness greater than 50.
- 20.1.4. With the exception of glass edges, there shall be no exposed rigid external edges where the predominant radii (i.e. ignoring transition and blending radii) are less than 3 mm.
- 20.1.5. For exposed rigid external edges, where the edge projects not more than 3,2 mm from the adjacent surfaces, the requirements for minimum radii shall not apply, provided that the height of the projection is not more than half its width and its edges are blunted.
- 20.1.6. There is no restriction on the use of alternatives to the specified or recommended dimensions where evidence of their suitability can be presented in terms of injury potential. The specified dimensions may be used as the basis for comparison.

20.2. Edge profile recommendations

- 20.2.1. For solid or framed partitions, where there are no exposed glass edges, the predominant corner radii (i.e. ignoring transition and blending radii) for all exposed rigid external edges should be:
- 20.2.2. For longitudinal partitions at least 10 mm and the exposed edge should have a minimum overall thickness of 35 mm unless the edge is shielded by a grab pole, grab rail or other feature.
- 20.2.3. For transverse partitions at least 5 mm, and the exposed edge should have a minimum overall thickness of 20 mm unless the edge is shielded by a grab pole, grab rail or other feature.
- 20.2.4. Partitions with exposed glass edges should be orientated in a transverse direction. Partitions with exposed glass edges shall not be orientated in a longitudinal direction. NOTE 1: Shielding provided by a grab pole, grab rail or the use of a resilient edge profile would no longer result in an exposed edge.
- 20.2.5. Exposed rigid external edges of luggage stacks and exposed rigid external edges on the undersides of overhead luggage racks should have radii of at least 10 mm, subject to the application of the formulae permitted by 6.2.2.3.
- 20.2.6. Exposed rigid external edges of interior panelling (for example corner joints between walls) should have radii of at least 10 mm, subject to the application of the formulae permitted by 6.2.2.3.

20.3. Projecting items

- 20.3.1. Wherever possible, concealed fasteners should be used to minimise the risk of injury due to secondary impact. The type and location of fasteners which are flush fitting or which are not concealed (for example countersunk, domed or standard screws or rivets) should be assessed to ensure the risk of secondary impact injuries is controlled.

21. Reuse, recycling

- 21.1. The product must allow reuse/remounting after demounting the panel.
- 21.2. The amount of different product varieties must be minimized/optimized to limit the amount of needed spare stock.
- 21.3. Different materials in the product must be able to be separated using conventional/industrial scale processing methods (e.g. heat, pressure, force) at the end of life.
- 21.4. Connections/adhesives in the product and for mounting the product must be reversible.
- 21.5. The product, product materials and mounting materials must be able to be recycled at the end-of-life.

B MATERIAL REPORTS

B.1 ALUMINIUM

Compocel_AL_FR_uk_Rev_12_b.pdf
Cellite-220-620-flyer-v2.pdf
Best Practice Guide for Sandwich Structu
aluNID-Data-Sheet.pdf
ALUCORE_TI_ProdInfo_EN.pdf
TRB-Rail-Brochure.pdf
Superflex - Technical-Specs-Eng
larcore_ENG.pdf
Corex-Data-Sheet-160mm-fold-English-'
Corex-Brochure-2019.pdf
Corex - Technical-Specs-Eng

B.2 PLASTIC

Nidaplast-COMP_CAT_UK_2017_BD.pdf
Econcore_leaflet_PLA-panelsfz.pdf
Econcore_A4LFT_Thermoplastic_Deman
Econcore_A4LFT_ThermhexLightwPolypı
Econcore_A4LFT_ThermhexLightwPolypı
DB-EN-PP8-120_PA7-07-G.pdf
DB-EN-PP8-100_PA7-04-G.pdf
DB-EN-PP8-85_PA7-54-D.pdf
DB-EN-PP8-80_PA7-01-H.pdf
DB-EN-PP8-60_PA7-10-E.pdf
COMP_FT_NIDAPLAST-8_UK_2017.pdf
Brochure_RPET_eng_Econcore_ThermHe
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