



Level 3 Industrial Case Study

Truck Trailer Lightweighting

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Summary

Granta EduPack provides a rational and systematic approach to materials selection which is invaluable to engineering and design. It also supports transparency in this process for the purposes of teaching and training. The available databases enable informed material choices in many specialized areas. In this advanced case study, we focus on materials decisions for transportation in order to reduce energy consumption of heavy goods vehicles.

The results show that a suggested end-grain Balsa sandwiched between Glass Fiber Reinforced Polyester face-sheets compares well with plywood and hardwood options when it comes to mechanical properties. The mechanical performance is verified independently in three-point bending lab tests. Lightweighting a trailer with the suggested sandwich panel decking saves around 300 kg of weight. This comes at a cost, as expected. Eco Audits show that the higher initial energy and economic costs are paid back in less than one year, by reduced fuel costs, in addition to the benefit of a lower CO₂ footprint.

Referenced websites were accessed at the time of the first publication date.

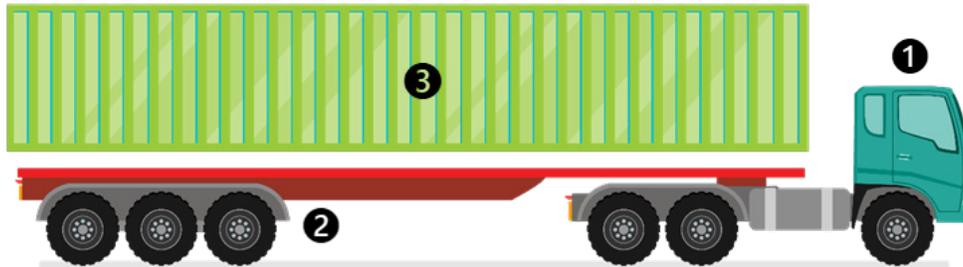
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1. What is the scope?

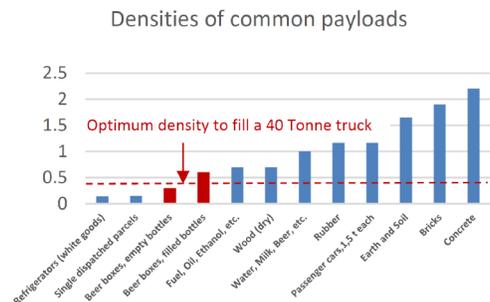
The Transportation sector is one of the largest contributors to global greenhouse gas emissions. Road freight is without doubt a major means of goods transportation, and one that is particularly difficult to make fossil-free. There is no indication that its contribution will be reduced in the foreseeable future. Today, Heavy Goods Vehicles (HGVs) over 3.5 tonnes account for almost a quarter of road transport CO₂ emissions, or some 6% of total EU greenhouse gas emissions. This is estimated to rise to 8% by 2020 [1].

The different parts of a European-style heavy goods vehicle are ① Truck, ② Trailer and ③ Transport load.



It has been noted that we can expect around a 6.5% reduction in fuel consumption just by reducing trailer unladen mass (see above) by 25% [2]. This may seem to be a modest reduction relative to improving logistical factors, such as running full by mass or running full by volume. However, the estimated reduction of 6.5% in fuel consumption from lightweighting is still significant enough to pursue. It has been suggested that reducing the unladen mass of the trailer is probably the easiest of the vehicle design changes to implement, hence this is the main focus of this case study.

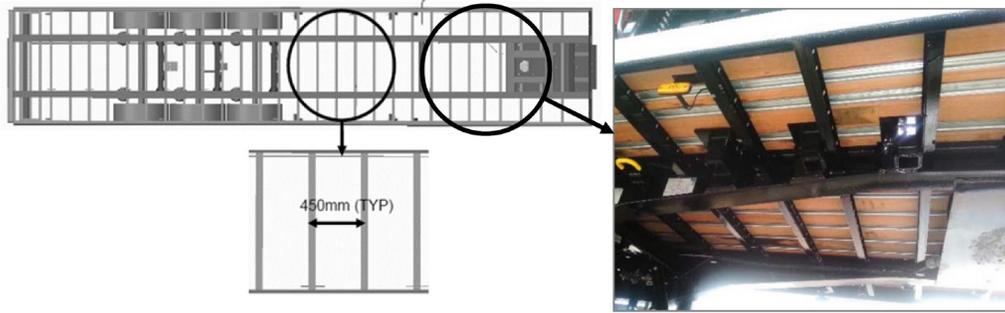
Logistically, the volume of the load is somewhat flexible but the maximum weight is not. The payload may be increased by the weight saved if the trailer weight is decreased. Some typical values of payloads are given in the diagram to the right [3]. The optimum density of the payload is typically somewhere between boxes of filled and empty beer bottles (closer to the empty...). Since the maximum weight of the load may increase by the weight saved on the trailer, the direct energy and emission reductions will come from the mileage of empty load.



The Table to the right shows the approximate weight contributions of major structural components in a 13.6 m flatbed road freight trailer [4], commonly found in Europe and shown in the picture above. It is evident that trailer decking, which is typically made of hardwood or plywood, contributes a significant proportion of weight and is therefore a good target for lightweighting. Using a lightweight deck in trailer design is also a significantly easier way to upgrade the existing fleet, compared to altering the design of steel chassis beams or the running gear. Another lightweighting action that is relatively easy to implement would be changing wheels from steel to aluminum or even CFRP.

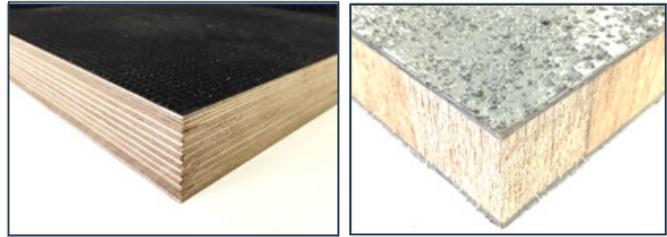
Trailer component	Approx. mass, kg	Approx. mass, %
Chassis beams and Structure	1800	43
Wheels and tires (6)	570	7
Running gear system (bogie)	1200	29
Decking	700	17
Scrub plate	150	4

A truck trailer deck commonly complies with the ISO1496 standard for cargo containers, and represents a surface area of approximately 27 m² for a 13.6 m trailer, as shown below. The typical thickness is 30 mm.



View of the trailer from the top without decking (left) and from underneath, with hardwood decking (right).

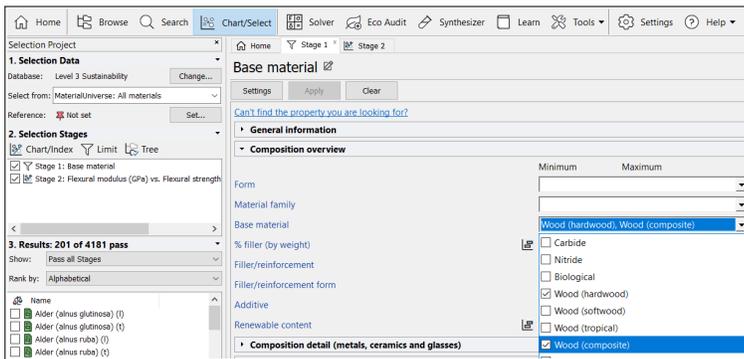
The structural configuration of a lightweight trailer deck could take many forms, including monolithic panels, plywood (left image), sandwich and hybrid panels (e.g., balsa-core sandwich panel, right image). The highly cost-driven nature of trailer construction, as well as the geometry of the conventional steel trailer chassis, makes sandwich panels strong candidates for use in this application.



A sandwich structure could help increase flexural strength and rigidity, while simultaneously reducing weight. Indeed, the structures of common road freight semi-trailers are strikingly similar to pedestrian bridges, where sandwich panel decks have been mounted on top of steel beams successfully. Sandwich panels are already replacing plywood panels in the side walls of box-type road freight trailers, which is also encouraging for their application to trailer decking.

2. What can you do with Granta EduPack?

Granta EduPack makes a systematic and comprehensive approach to material selection possible. This is based on the work of Professor Mike Ashby [5] and coworkers. The data and the tools that come with the software enables a proper investigation into alternatives for lightweight decking as well as benchmarking of the options. There are more than 500 types of wood in the Level 3 databases and models for laminated as well as sandwich panel

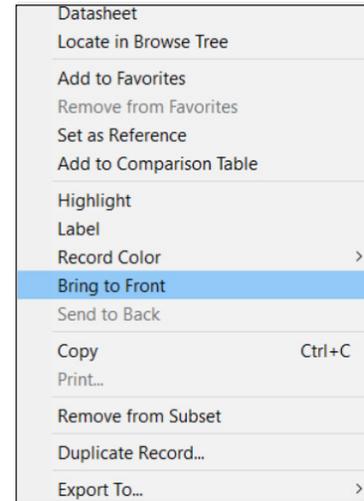
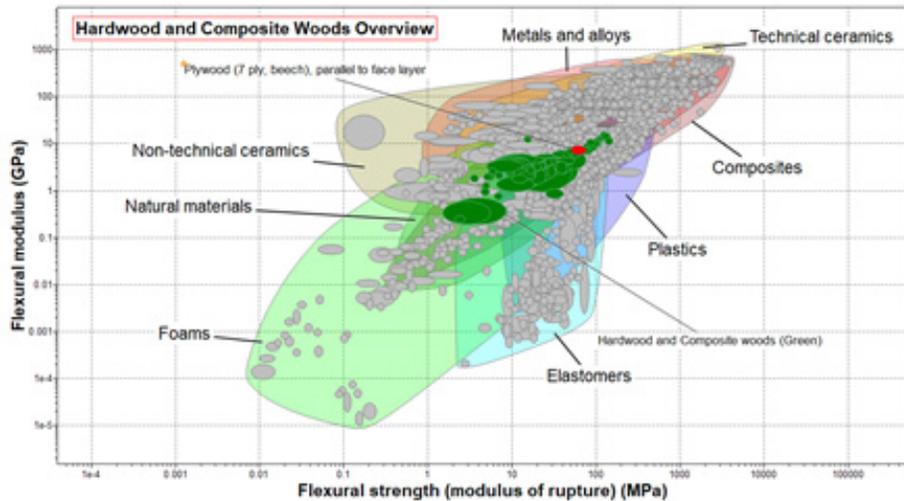


structures in the Synthesizer tool, available in the advanced subject editions. We will use the Sustainability database, as it contains both the Synthesizer tool for estimating properties of structural hybrids and the enhanced Eco Audit tool for assessment of life-cycle benefits of the lightweight decking.

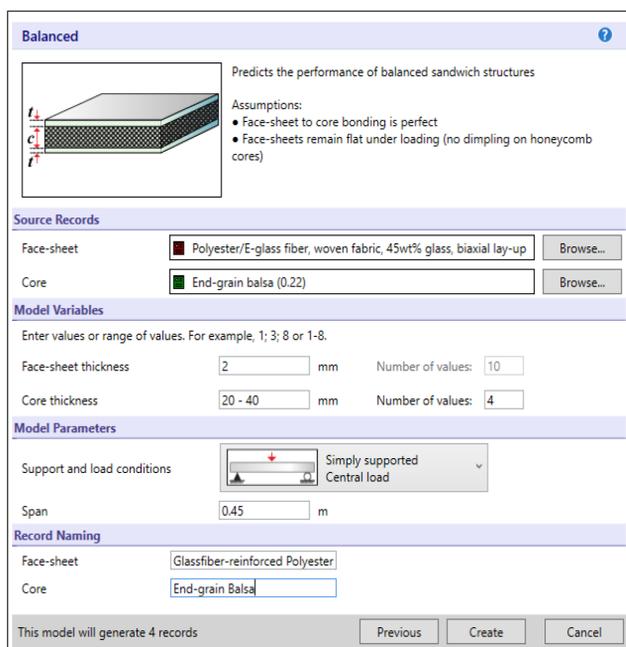
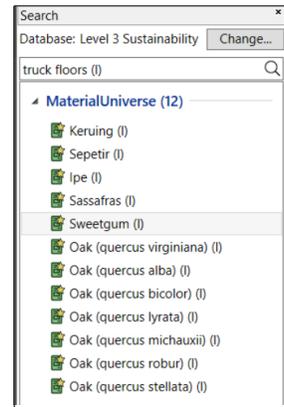
The approach of this study is to find materials that already meet the design requirements and compare these materials with each other

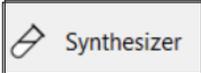
and with new candidates. This can stimulate discussions on design decisions in class. We start by considering wood-based materials that are similar to those already used as truck trailer decking. For an initial overview, choose the *MaterialUniverse: All bulk materials* subset after clicking *Chart/Select* in the main toolbar. Then use the filter in the *Limit* stage, where the composition overview allows screening for hardwoods and composite woods (plywood, chipboards etc). This results in nearly 70 realistic wood options. An overview plot can now be created by using the *Chart* tool button. Since it is easy to modify or add Chart stages, we start by plotting *Flexural stiffness vs Flexural strength* for general mechanical performance.

We will use plywood as a reference for decking, as it is very commonly used. The *Search* function can be used to find **plywood (7-ply)**, which can be added to *Favorites* by right clicking. Right-clicking also lets you Label this record, change Record Color for this material to red and use the function to *Bring to Front* for visibility.



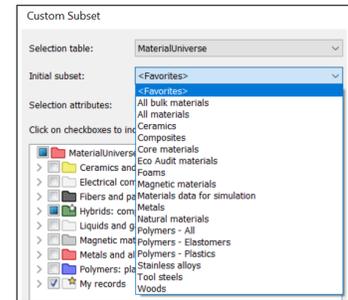
The chart above (with family envelopes) shows that woods, and particularly plywood, perform well in these relevant properties for decking. In the next step, we narrow the selection of woods to include only the ones that actually appear as truck flooring material in the datasheets. A search for **truck floors** renders 24 wood and 8 aluminum records. Note that all woods appear twice, since their properties are anisotropic and there are separate records for transverse (across) properties and longitudinal (along). We therefore go back to the Search window and add "(l)", as shown to the right, in order to eliminate the metals and (inferior) transverse (t) datasheets. This reduces the results to a dozen woods, all used for truck flooring. We then use shift-click to mark all these records and then right-click to *Add to Favorites*. Favorites now contain these 12 materials plus the previously added plywood. Finally, we create and add one more decking option that represent a realistic sandwich panel, as suggested previously.



To generate lightweight deck options, we invoke the Synthesizer  tool, available in some advanced databases of Granta EduPack. It provides models to estimate properties for some structural hybrids, such as balanced sandwich panels, that can be visualized. The face material is a Glass Fiber Reinforced Polyester, 45 wt% biaxial lay-up, found under Hybrids... > Composites > Polymer matrix... End-grain balsa is found under Hybrids... > Composites > Natural material composites > Woods... The load is chosen to be a simply supported panel with a point load, representing a truck. The span is taken from actual trailer data, 0.45 m. The core thickness ranges around actual samples (25.4 mm) tested and reported in research [6]. After filling the *Record Naming*, a datasheet with a number of estimated properties is generated and located in a special folder in the Browse Tree, called My Records. This and the 13 Favorite materials can now be plotted and compared thoroughly.

3. Using Granta EduPack to compare and Benchmark materials

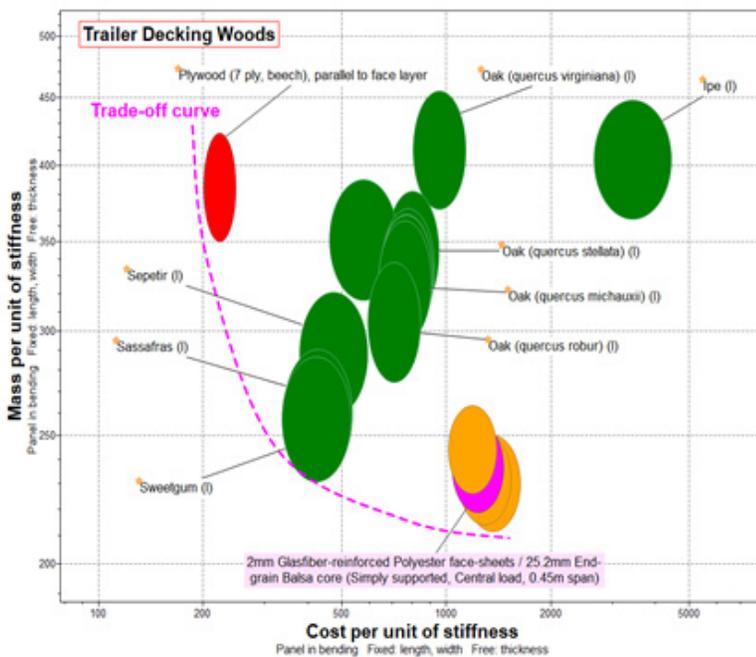
When making the chart, the Favorites can be selected as a *Custom Subset* in the “Select from:” drop-down menu, which makes them easy to plot. My records or the synthesized record therein can be included explicitly in the Custom subset, as shown to the right. A chart is subsequently plotted using *either the Performance Index Finder* or the *Advanced* function button in the Chart stage dialog box. This enables a function editor that allows you to specify a performance index for minimum mass, **M1**, and for minimum cost, **M2**, respectively. It is a **Stiffness-Limited Design**, since we want the deck to deflect as little as possible.



In order to visualize the options, we plot the performance indices for minimum mass and cost, respectively. The **Function** corresponds to a *stiffness-limited design* of a panel in bending, assuming the thickness to be the free variable. The **Constraints** are already implemented, since we are primarily looking at a subset of materials already in use.

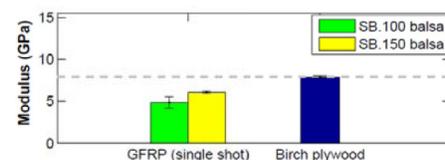
The **Objectives** for the performance are given by the indices found under the *Learn* button or by the Performance Index Finger.

Stiffness-limited design at minimum mass



In the chart to the left, we have plotted **M1** = Density / Flexural Modulus ^(1/3) on the Y-Axis and **M2** = Price * Density / Flexural Modulus ^(1/3) on the X-Axis. The comparison shows that Plywood is, indeed, the cheapest option per bending stiffness. Common hardwoods, such as *Keruing* and *Oak* have comparable mass performance but are more costly. The *sandwich panels* that were synthesized, are estimated to be the lightest options but also more expensive than, *e.g.*, *Oak*. Both *Plywood* and the *sandwich panels* are at the Pareto front (Trade-off curve) indicated in the chart using the Annotation tools. The 25.2 mm balsa core sandwich (shaded) appears to be a good compromise, as a thicker core is more costly and a thinner one denser.

The quality of the estimated material property data of the sandwich panel is good, as indicated by test data on a very similar (1-inch core) system, shown here. The sandwich panel indicated above gives an estimated bending stiffness, E_p of 4.47-6.36 GPa (synthesized datasheet), which is in close agreement with real measurements of an equivalent system (*yellow bar*, 2 mm GFRP/25.4 mm End-grain SB 150 Balsa/2 mm GFRP). The datasheet of *7 Ply Beech Plywood*, gives E_f =6-9 GPa also compare well with the tested birch plywood, shown in the test data (*blue bar*) [6].



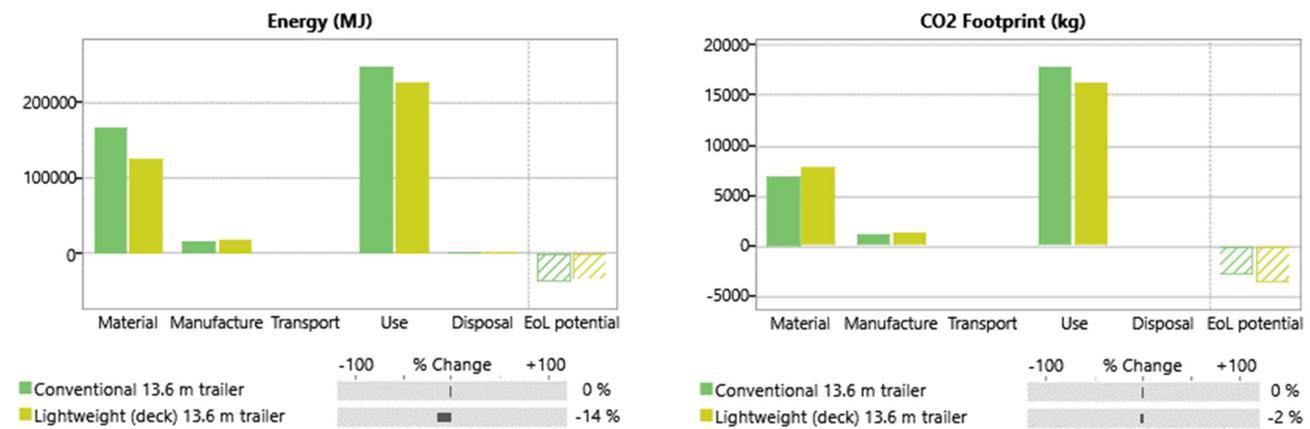
4. Eco Audit of a lightweight unladen truck trailer

By replacing a few structural components, significant reductions in mass can be achieved. We have used the Enhanced Eco Audit tool to investigate the life-cycle benefits of moderate lightweighting, in comparison to a standard trailer. Simplified Bill of Materials (BOM) for these cases are given below, first the reference trailer with hardwood decking:



Components					
Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process
1	Chassis beams	High strength low alloy steel, YS355, hot rolled	Typical %	1800	Roll forming
1	Running gear system (bogie)	High strength low alloy steel, YS350, cold rolled	Typical %	1200	Roll forming
1	Decking	Keruing (I)	Virgin (0%)	685	Incl. in material value
1	Scrub plate	Carbon steel, AISI 1080, as rolled	Typical %	150	Roll forming
6	Tyres	Styrene butadiene rubber (SBR, 30% carbon black)	Virgin (0%)	50	Polymer molding
6	Wheels	High strength low alloy steel, YS350, cold rolled	Typical %	45	Roll forming

The Eco Audit summary charts for Energy and CO₂ footprint *in Europe* are shown below. The dark green bars represent the reference trailer. If the mobile use phase is set to: 1 year, 200 km per day, 300 days / year by 32-tonne commercial diesel truck, the materials represent over 30% of the total life-energy of the trailer and the use phase almost 60% the first year. As can be seen, there is a close relationship between the energy use and the CO₂ emissions. The weight of a conventional decking ranges from 606 kg (plywood) to 689 kg (keruing), using a thickness of 0.030 m and area of 27 m². As usual, eco-data has much greater uncertainty than mechanical.



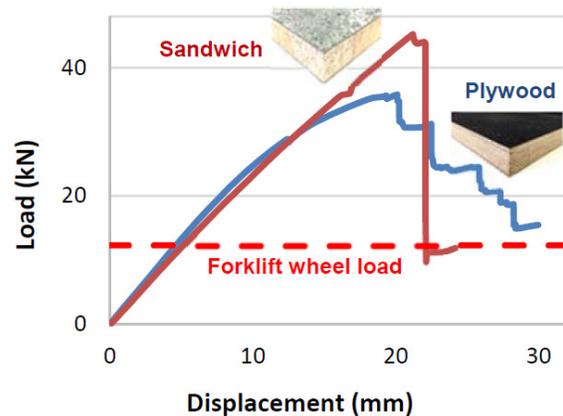
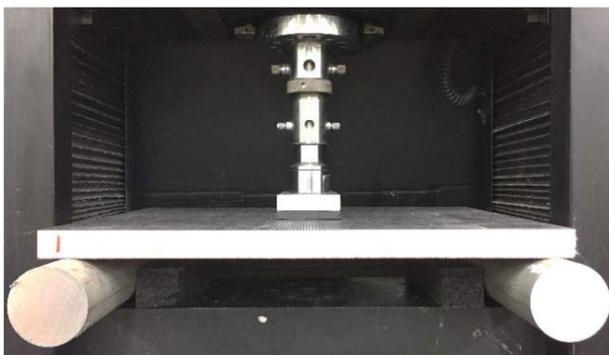
The moderate lightweight case is represented by the yellow/light green bars, above. The BOM for this case reflects a 330 kg sandwich panel decking as possible material replacement, resulting in a weight reduction by approximately half. It can be seen in the Eco Audit above that the gains made in the use phase (also 200 km per day, 300 days first year) more than offsets the increase in energy use during the material production and manufacturing phase. In total, the lightweighting results in an estimated 14% less energy and also slightly less CO₂ footprint. And this is based on only 1 year of use. If 5 years use is assumed, the estimated energy reduction is lower: 10%, but the CO₂ footprint reduction is higher: 6%

Components					
Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process
1	Chassis beams	High strength low alloy steel, YS355, hot rolled	Typical %	1800	Roll forming
1	Running gear system (bogie)	High strength low alloy steel, YS350, cold rolled	Typical %	1200	Roll forming
1	Decking	End-grain balsa (0.22)	Virgin (0%)	159.1	Incl. in material value
2	Decking	Polyester/E-glass fiber, woven fabric, 45wt% glass, biaxial lay-up	Virgin (0%)	83.7	Resin transfer molding (RTM)
1	Scrub plate	Carbon steel, AISI 1080, as rolled	Typical %	150	Roll forming
6	Tyres	Styrene butadiene rubber (SBR, 30% carbon black)	Virgin (0%)	50	Polymer molding
6	Wheels	High strength low alloy steel, YS350, cold rolled	Typical %	45	Roll forming

5. Analysis and reality check

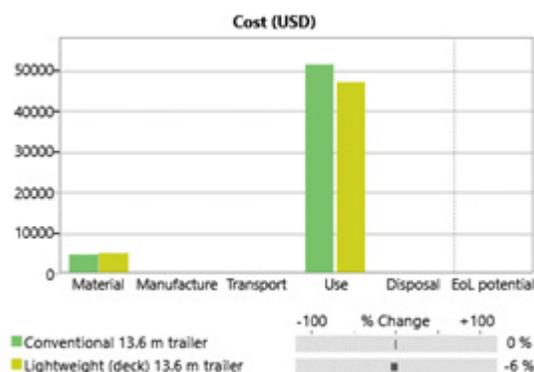
In this Advanced Industrial Case Study, we have departed slightly from the traditional materials selection methodology, screening and ranking of a large number of materials. This systematic methodology is mainly used when selecting a material for a new product. In the Truck trailer lightweighting case, we are predominately interested in improving an existing material in a fixed application, which represents a constrained design. We passed the screening by simply restricting the choice to existing materials and used these to benchmark a new candidate, suggested by research. In plotting the objectives in conflict, we assumed the thickness to be a free design parameter, which is not strictly the case if the geometry is nearly fixed. In addition to benchmarking the suggested hybrid structure visually in the chart, we must therefore verify that the mechanical properties at the given thickness are sufficient.

Sandwich panels with woven Glass Fiber Reinforced Polyester and an end-grain balsa has been found to be the most advantageous material combination in terms of both raw material cost and mechanical performance. These panels can be fabricated using a single shot fabrication technique and are approximately 45% lighter than conventional plywood trailer decking. The properties of the fixed thickness (around 30 mm) sandwich panel has been tested under controlled conditions using three-point bending tests at room temperature [6].



The ISO 1496 standard prescribes a scenario resulting from the wheel load of a fork lift. The load is indicated by a dashed red line in the diagram above [6]. As can be seen, the sandwich panel passes the test, surpassing the plywood sample that represents a currently used decking, before failure occurs, confirming the safety.

As the trade-off plot in Section 3 shows, the sandwich panels are significantly higher in cost per stiffness than the alternatives, as measured by the *performance index M2*. It is not easy to estimate how much more expensive it is in relation to the fuel savings resulting from the mass reduction. One way to have a quick estimate of the cost benefits, is to look at the Cost Audit, supplied optionally by the Enhanced Eco Audit.



A rough idea of the savings in a life-cycle perspective is given in the Eco Audit (more detailed data can be extracted from the Eco Audit report supplied by Granta EduPack). It confirms that the Hybrid structure is more expensive in materials cost and manufacturing but, that the total cost is about the same due to lower fuel costs. Over a 5-year period, the saving is estimated to 6%, as can be seen to the left. The country of use in the Eco Audit will affect the fuel prices so, for example, if USA is selected instead of Europe, the fuel costs decrease, reversing the economic benefit over the first year (+3%). For 5 years, though, the total economic benefit is 4%.

6. What does Granta EduPack bring to the understanding?

Granta EduPack is an excellent resource for teaching the design process, working with interactive visual tools. The educator can easily show how to make good materials decisions and students can explore ways to select and assess materials in realistic projects. Our *Advanced Industrial Case Studies* are intended to inspire and guide product development, provide necessary knowledge and facilitate the understanding of the subject.

In this case study, Granta EduPack suggests the following conclusions on truck trailer lightweighting:

- The Sustainable Development database has a large number of specialized materials and data organized into useful subsets, we have successfully explored woods for trailer decking. It also provides advanced tools that were particularly useful in this case.
- The *visualization tools* quickly let us have an overview of material properties to compare different options for truck trailer decking, showing, for example, that plywood is a very competitive alternative.
- The *synthesizer tool* could be used to create estimated data for new sandwich panel options, suggested by research, and this could be benchmarked against existing materials in use.
- The *Enhanced Eco Audit* helped us to estimate the life-cycle benefits of the new hybrid panel in terms of *Energy, CO₂ footprint and Cost*. One should be aware of large uncertainties of eco-properties.

The results show that the suggested End-grain Balsa sandwiched between Glass Fiber Reinforced Polyester face-sheets compares well with plywood and hardwood options when it comes to mechanical properties. This is verified independently in three-point bending tests. A lightweight trailer with Aluminum alloy wheels and the suggested sandwich panel decking has around 300-400 kg less unladen weight than plywood or hardwood. This comes at a cost, as expected. Eco Audits show, however, that the higher initial energy and economic costs are paid back in less than one year, by cheaper fuel bills, in addition to lower CO₂ footprint.

Acknowledgments

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